GRIZZLY BEAR POPULATION SURVEY IN THE CENTRAL PURCELL MOUNTAINS, BRITISH COLUMBIA

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EXECUTIVE SUMMARY

The Government of British Columbia is in the process of reviewing potential environmental impacts from development of the proposed Jumbo Ski Resort in the Purcell Mountains of south-central British Columbia. The proposed development, situated in the Jumbo Creek valley and approximately 30 km west of Panorama ski resort, would offer winter skiing, summer skiing, mountain biking and hiking. At full build out, the proposed facility would have 7,000 bed units (6,500 bed units for visitors and 500 for staff). The design is for a compact grouping of small-scale buildings in a pedestrian environment covering about 30 hectares (75 acres).

Grizzly bears are part of the Purcell Mountain's ecosystem and are sensitive to effects of human activities and development. In order to help estimate the significance of effects of the proposed development on grizzly bears in the Purcells, an estimate of the size and seasonal distribution of the grizzly bear population was required. Information on the size and distribution of grizzly bears in the Central Purcell Mountains was also intended for use in the comprehensive environmental impact assessment and cumulative effects assessment of the proposed Jumbo Resort development.

AXYS Environmental Consulting Ltd. was retained to conduct surveys and estimate the abundance and seasonal distribution of grizzly bears in the Central Purcell study area, which encompasses the proposed development. The Central Purcell study area is defined by the heights of land of the headwaters of Stockdale, Horsethief, Toby, Glacier and Hamill creeks. The approach used to generate the population estimate was based on collection of hair samples, analysis of DNA obtained from hair samples, and genetic identification of individual bears.

Primary results of the survey include the following:

1. the unbounded population estimate for the Central Purcell study area and surrounding area was 45 grizzly bears with a 95 percent confidence interval of 37 – 68 grizzly bears;

2. 33 individual bears were identified from the hair samples including 18 females, 10 males, and 5 of unknown sex. Approximately ½ of the bears were recaptured at least once;

3. grizzly bears were sampled throughout the study area; distribution of hair captures was non-uniform with least success obtained in the lower and middle Horsethief Valley in the northeastern quadrant of the study area;

4. female captures were relatively evenly distributed in those drainages where grizzly bear presence was confirmed. Of the 18 female grizzly bears found in the Central Purcell study area, five were captured in the Glacier Creek watershed, three in Stockdale Creek, three in lower Toby Creek including Mineral and Coppercrown creeks, three in upper and south Toby Creek drainages, two in the Jumbo Creek watershed, and one female grizzly bear in each of Farnum and Hamill Creek watersheds. The number of females reported captured confirm these as minimum numbers to have been using these valleys at the time of the survey; greater numbers of female grizzly bears may occur in each of these valleys.

5. the majority of male grizzly bears were sampled from within the southern one third of the study area, specifically in Hamill, Upper Toby, South Toby, Mineral and Coppercrown creeks. The lack of male grizzly bear captures at trap sites in Jumbo, Stockdale, Lower Horsethief, McDonald, Law and Bruce creek valleys confirms only a lack of capture success at these sites as opposed to potential absence from these valleys.

6. the study area is not closed to grizzly bear movements, suggesting that bears were leaving or entering the study area during the sampling period; and

7. many of the bears in adjacent watersheds in the study area are related to each other.

The data provided by this survey show that there is a currently viable resident population of grizzly bears occupying the Central Purcell study area. History and extrapolation from other research efforts in the region suggest that there will be impacts associated with the development. However, a comprehensive assessment of impacts and potential mitigation measures will be required in order to attempt to quantify and estimate the significance of post-mitigation, project-specific impacts and project-related cumulative impacts on grizzly bear populations and habitats.

1.0 INTRODUCTION

1.1 Overview of the Proposed Jumbo Glacier Alpine Resort Development

Pheidias Project Management Corporation (Pheidias) is proposing to develop the Jumbo Glacier Alpine Resort at Jumbo Creek, B.C. The primary recreational activity at the resort will be downhill skiing. The project was proposed by Pheidias Project Management Corporation for a group of investors registered as a Canadian Partnership called Glacier Resorts Ltd., of Vancouver.

The site of the proposed project is approximately 30 km west of the Panorama ski resort in the Jumbo Creek Valley of the Purcell Mountain range, accessible along an existing gravel road from Invermere, B.C. The goal of the proposed project is to develop a facility offering winter and summer skiing, hiking, and biking. This project includes plans for the establishment of facilities with capability for 6,500 bed units, an additional 500 bed units for staff, and an associated downhill ski facility in the valley of Jumbo Creek. The proposed village would encompass 30 ha (75 acres) of land at the site of an abandoned sawmill. With a village base elevation of approximately 1,700 meters (5,500 feet), the resort would be able to operate year round with glacier skiing available at elevations in the 3,000 meter (9,900 feet) range throughout the summer and access to other recreational activities such as sight-seeing and hiking. Upgrading the existing road from the Mineral King Mine to the project site would provide access to the site.

1.2 Regulatory Setting

The proponent first made application for the proposed resort development in August 1991 in response to a government call for proposals for resort developments on Crown Land (Pheidias Project Management Corporation 1997). In 1995, project supervision then under the Commercial Alpine Ski Policy was handed to the recently established British Columbia Environmental Assessment Office (EAO) for review and direction. Concerns were immediately raised by Kootenay-based environmental interests (including the East Kootenay Environmental Society and the general public) and by British Columbia's Ministry of Environment, Lands and Parks, concerning the project's potential for direct and indirect impacts on grizzly bear (*Ursus arctos*) populations in the region encompassing the project area. Subsequently, British Columbia's Environmental Assessment Office (EAO) and Ministry of Environment, Lands and Parks (MELP) coordinated efforts to develop environmental impact assessment Terms of Reference, which included explicit aspects regarding grizzly bears. These Terms of Reference were required to be fulfilled by the Proponent as part of the Stage II provincial environmental regulatory process.

There are two land use designations within and/or adjacent to the site of the proposed development that are particularly relevant to consideration of grizzly bear population and habitat management. First, the Jumbo-Upper Horsethief watershed has been identified in the East Kootenay Land Use Plan (EKLUP) as a special management area (CORE 1994). This designation is intended to provide for the maintenance of important wildlife, wildland and recreational values within an area that has been significantly disturbed through forest harvesting practices (CORE 1994). The primary management goals for the area are to maintain substantial tourism and recreational values while maintaining the wilderness character of the area (CORE 1994). Within the southern half of the Central Purcell study area is the Purcell

Wilderness Conservancy Provincial Park. The Conservancy lands are also located immediately south of Jumbo Valley, the location of the proposed Jumbo Resort development. This Park occupies 199,683 ha and has been identified in the EKLUP as being "virtually undisturbed" and requiring of protection "to maintain the viability and diversity of one of the largest intact ecosystems in the southeastern BC." The "virtually undisturbed" ecological state of the Purcell Wilderness Conservancy allows for the current provision of important habitats for several wildlife species, including grizzly bear (BCMELP 1999).

1.3 Objectives

In 1998, AXYS Environmental Consulting Ltd. was retained by British Columbia's Environmental Assessment Office and the project proponent to undertake an inventory of bears in the Central Purcell study area. Using DNA analysis of hair samples, the study was undertaken in spring and summer of 1998 and was designed to estimate the size and seasonal distribution of the grizzly bear population in the Jumbo Creek, Horsethief Creek, Toby Creek, Glacier Creek and Hamill Creek valleys. Objectives for the study were provided by MELP as Point 12, Section D.3 (c) in the Final Project Report Specifications for the project, dated May 20, 1998. Point 12 stated:

"Population Monitoring through Genetic Testing

12. Monitor and report on the potential direct and indirect effects of the project to predict, detect and assess changes (if any) in grizzly bear numbers and distribution. The monitoring program is to include:

- field collection of hair samples of grizzly bears within the area of expected direct and indirect impacts for one field season (approximately June 1 through July 31) prior to the completion of the project report, genetic analysis of the hair samples to identify individual bears, interpretation of the hair analysis data to assist in the prediction of potential direct and indirect impacts of the project on grizzly bears, and to establish a baseline for future monitoring, and reporting of findings in the project report; and

- if the project is approved under the *EA Act*, continued field collection of hair samples from grizzly bears within the area of direct and indirect impacts during final project planning and construction (and thereafter for 10 years, or until such earlier time as MELP determines that it is no longer required), genetic analysis of the hair samples, interpretation of the hair analysis data to detect and assess changes (if any) in grizzly bear numbers and distribution in response to project construction and operation, and reporting of the findings to MELP. "

This overall goal for the grizzly bear survey was used to derive more specific objectives that included:

1) field collection of hair samples of grizzly bears;

2) genetic analysis of the hair samples to identify individual bears;

3) interpretation of the hair analysis data;

4) development of an unbounded population estimate of the numbers of bears using the Central Purcell Study Area and a description of their seasonal distribution by sex; and

5) to summarize all results in a final report to provide baseline data for a long term monitoring effort, if required, and for use in the provincial required comprehensive impact assessment for the proposed project.

The main focus of this report, as directed by the Terms of Reference, was to report on results of hair analyses and estimate and discuss the size and distribution of the grizzly bear population in the Central Purcell Mountain region. This project and report do not address a comprehensive Project Environmental Assessment Study as required by the EA. Recommendations for an Environmental Assessment are provided in Section 5.4 of this report.

2.0 SETTING

2.1 Study Area Boundaries

The Central Purcell Mountains survey area covers 1,650 km^2 and is defined by the heights of land encompassing most or all of Stockdale, Horsethief, Toby, Glacier and Hamill creeks (Figure 1). The Central Purcell survey area was delineated based primarily on the need to:

- include an area that would encompass potential direct and indirect effects of the proposed resort development on grizzly bears; and
- cover an area large enough to contain enough grizzly bears to produce a statistically reliable population estimate.

2.2 Ecological Setting

2.2.1 Regional Ecological Perspective

The study area is located in the Central Purcell Mountains of south-central British Columbia, characterized by rugged mountains, narrow, steep-sloped valleys and numerous glacier formations. The study area sits within the northern parts of Purcell Mountain Range and extends east toward the Columbia River Valley, and westward into the Kootenay Lake watershed.

The physiographic and climatic variables combine to create habitat mosaics and remote wilderness environs, which are highly suitable as grizzly bear habitat. Notably, the Purcell Mountain Range exhibits an effective orthographic uplift effect making the windward side of the range one of the wetter areas in the interior of BC, while the leeward side is significantly influenced by a rainshadow effect.

This Central Purcell study area includes five different biogeoclimatic zones. In the west of the study area and surrounding Duncan Lake is the Interior Cedar Hemlock biogeoclimatic zone (ICH). Specifically, this is the moist, warm (mw) subzone which includes the Hamill Creek and Glacier Creek watersheds, up to approximately 1500 m elevation (Ketcheson et al. 1991). As part of the Interior Wet Belt, the winter climate of the ICHmw subzone is relatively wet and cool with a heavy snowpack in winter, while the summers are warm and dry (DeLong et al. 1991). Typical characteristics of this zone include dense western red cedar and western hemlock coniferous forests with Douglas-fir in the drier areas. This zone is generally rich in large mammal species, owing in part to the occurrence of old growth timber stands and lush vegetation (i.e., succulent plants as forage by grizzly bears) (Ketcheson *et al.* 1991).

The Columbia River Valley, located to the east of the study area is comprised of the Interior Douglas-fir biogeoclimatic zone (IDF). This zone extends along the entire valley floor and enters the study area up the Horsethief and Toby Creek valleys to approximately 1450 m elevation. The main climate-controlling factor in the IDF is its location in the rainshadow of the Purcell Mountains. Within the study area, where the IDFdm subzone, a dry and mild climate is expected where moisture deficits often occur towards the end of the summer (Hope *et al.* 1991a).

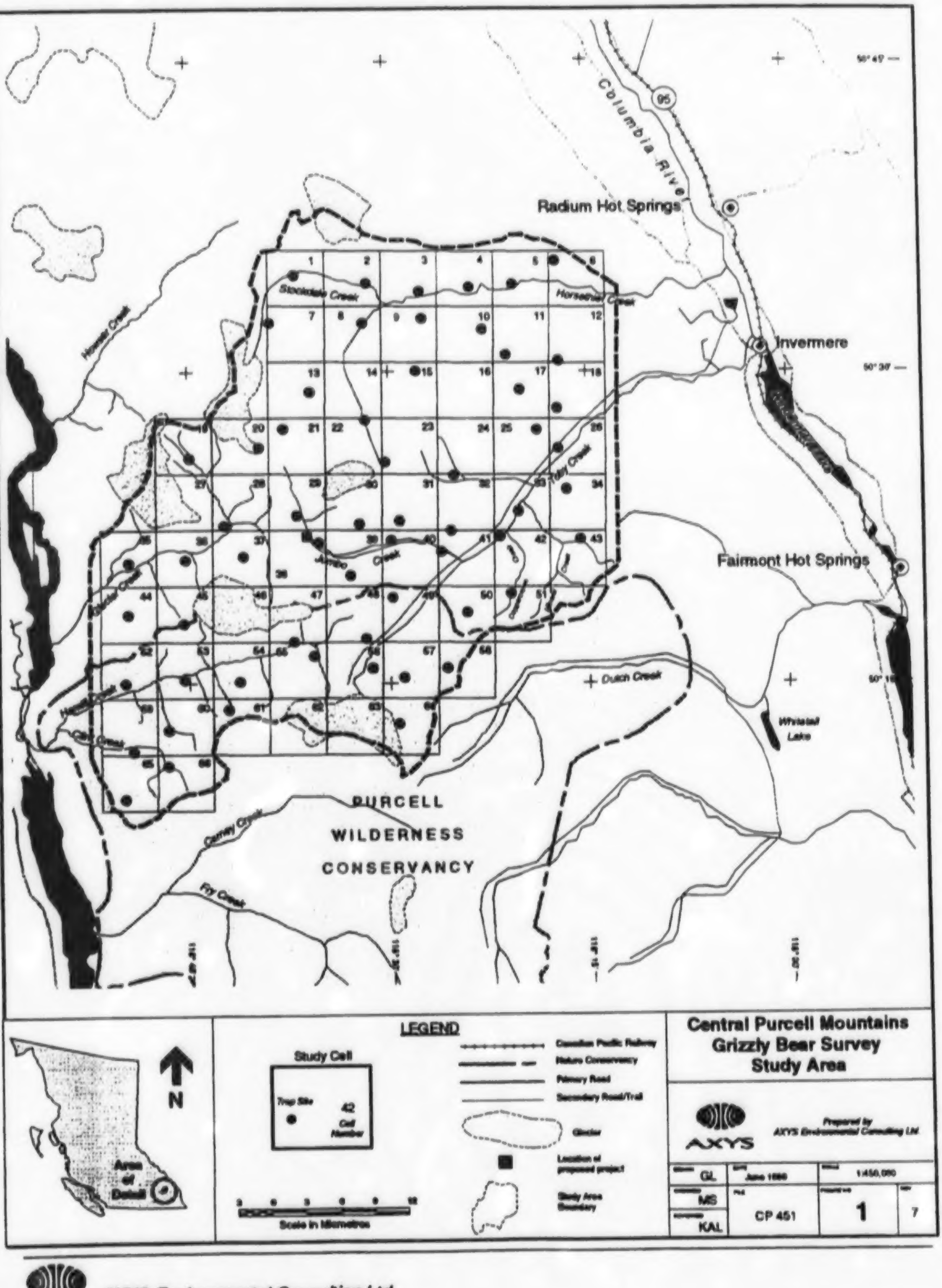
Above the IDF biogeoclimatic zone of the Columbia River Valley floor lies the Montane Spruce (MS) biogeoclimatic zone. This zone exists on the drier leeward side of the Purcell Mountains and is characterized by white spruce and subalpine fir climax forests and fire-related seral stands of lodgepole pine (*Pinus contorta*). Typical understory species include black huckleberry (*Vaccinium membranaceum*), Utah honeysuckle (*Lonicera utahensis*) and grouseberry (*V. scoparium*) (Hope *et al.* 1991b). The subzone particular to these mid-elevational areas of the Rocky Mountain Trench is the MSdk, which reflects the dry (due to rainshadow effects) and cool nature of the zonal climate.

Also within the study area, specifically above the MS in the east and the ICH to the west, is the Engelmann Spruce—Subalpine Fir (ESSF) biogeoclimatic zone. This zone is found at mid-to-upper elevations below the Alpine Tundra biogeoclimatic zone. The ESSF is generally found in rugged and mountainous areas and has a relatively cold and moist climate where snow is generally heavy in winter. Often the ESSF is found as a fully forested zone at lower elevations, which thins out to become parkland at higher elevations. The dominant tree species include: Englemann spruce (*Picea englemanni*), subalpine fir (*Abies lasiocarpa*) with whitebark pine (*Pinus albicaulis*), limber pine (*Pinus flexilis*) and alpine larch (*Larix lyallii*) also found there (Stewart and Wikeem 1991).

High snowfall areas with extensive avalanche tracks are common within the Columbia Mountains and Highlands Ecoregion (Campbell et al. 1990), which includes the Central Purcell study area. These form critical components of the grizzly bear habitat because of the provision of the high-protein and high-energy diets required for growth. This diet may include lush herbaceous vegetation and abundant huckleberry and blueberry patches, which are readily available in the ICH and ESSF (Ketcheson et al. 1991).

The Alpine Tundra (AT) biogeoclimatic zone is found at the highest elevations with the study area (generally above 2250m). Minimal tree coverage, and the presence of dwarf trees, or "Krumholz", at lower zone elevations generally characterize the AT. Krumholz trees can be one of many species but are often either subalpine fir, Engelmann spruce, white spruce, mountain hemlock or whitebark pine. Other alpine vegetation includes shrubs, herbs, bryophytes and lichens. In the alpine areas vegetation is subject to all the extremes of the physical environment, including factors such as topographic exposure, wind, solar radiation, soil temperature, and the distribution of snow and its meltwater (Pojar and Stewart 1991). Additionally, much of the study area in this zone is dominated by rock, ice and snow (i.e., Jumbo Glacier).

Figure 1. Central Purcell Mountains Grizzly Bear Survey Study Area



2.2.2 Jumbo Glacier Alpine Resort Perspective

The Jumbo Glacier project study area is located within the rugged mountainous terrain of Columbia Mountains and Highlands Ecoregion (CMH), which, in turn, is located within the Southern Interior Mountains Ecoprovince (Demarchi 1993). The Central Purcell study area, including the proposed village site and associated facilities, cover three ecosections within the CMH, including the Northern and Southern Columbia Mountains and the Eastern Purcell Mountains.

2.2.3 Population Status and Distribution of Grizzly Bears

Continentally, grizzly bear numbers have declined dramatically within western North America during and previous to this century (IGBC 1987; Banci 1991; US Fish and Wildlife Service 1993). Within the contiguous states south of the international border, populations have been reduced more than 90% from estimated distributions prior to European presence on the continent (USFWS 1993). There is a history of mutual intolerance between humans and grizzly bears, and most of the bears that have survived in southeastern British Columbia and western Alberta inhabit the more remote mountain ranges that have not been subjected to intensive development by humans. Grizzly bears have been extirpated from the Canadian prairies, central and eastern Alberta (Neilson 1975; Banci 1991), several areas across southern B.C., the southwestern lower mainland and the central Okanagan region extending north to Prince George (McLellan 1998). Two populations, one in the North Cascade ecosystem around Manning Park and the other in the Granby-Kettle area, are likely isolated (McLellan 1998).

2.2.3.1 Grizzly Bear Populations in Southern British Columbia and Northern Montana Ecosystems

Studies of grizzly bears in southeastern British Columbia and northwestern Montana have resulted in density estimates of grizzly bears that have generally ranged between 1.4 and 6.4 bears for every one hundred square kilometers. McLellan (1989b) found a relatively high average density of grizzly bears ($6.4/100km^2$) through saturation trapping and radio-telemetry in a multiple use area in the north fork of the Flathead watershed in the Rocky Mountains of southeastern British Columbia. An annual population growth rate of approximately 8% suggested that the grizzly bears in this study area were acting as a source for surrounding areas (McLellan 1989b; Hovey and McLellan 1996). Wielgus *et al.* (1994) estimated grizzly bear population densities of $2.3/100km^2$ in the southern Selkirk mountains of British Columbia and $1.4/100km^2$ within the same mountain range in Idaho. South and east of the Central Purcell study area, Mace and Waller (1999) found average densities of $2.5/100km^2$ in the Swan Mountains of northwest Montana, and considered the population to be "tenuously stable".

Recent use of DNA based mark-recapture methods have generated two unbounded population estimates within the Kootenay region of British Columbia. The West Slopes Bear Research Project straddles the Selkirk, Purcell, and Rocky mountain ranges that surround Golden, BC. This area includes both multiple use lands and protected park land. The unbounded population estimate for the 4096 km^2 study area is 104 animals (Woods *et al.* 1997). The study area is open to grizzly bear movements and results have not yet been used to generate a density estimate. Mowat and Strobeck (1999) estimated the population in the central Selkirks to be 258 grizzly bears within a 10,000 km^2 study area.

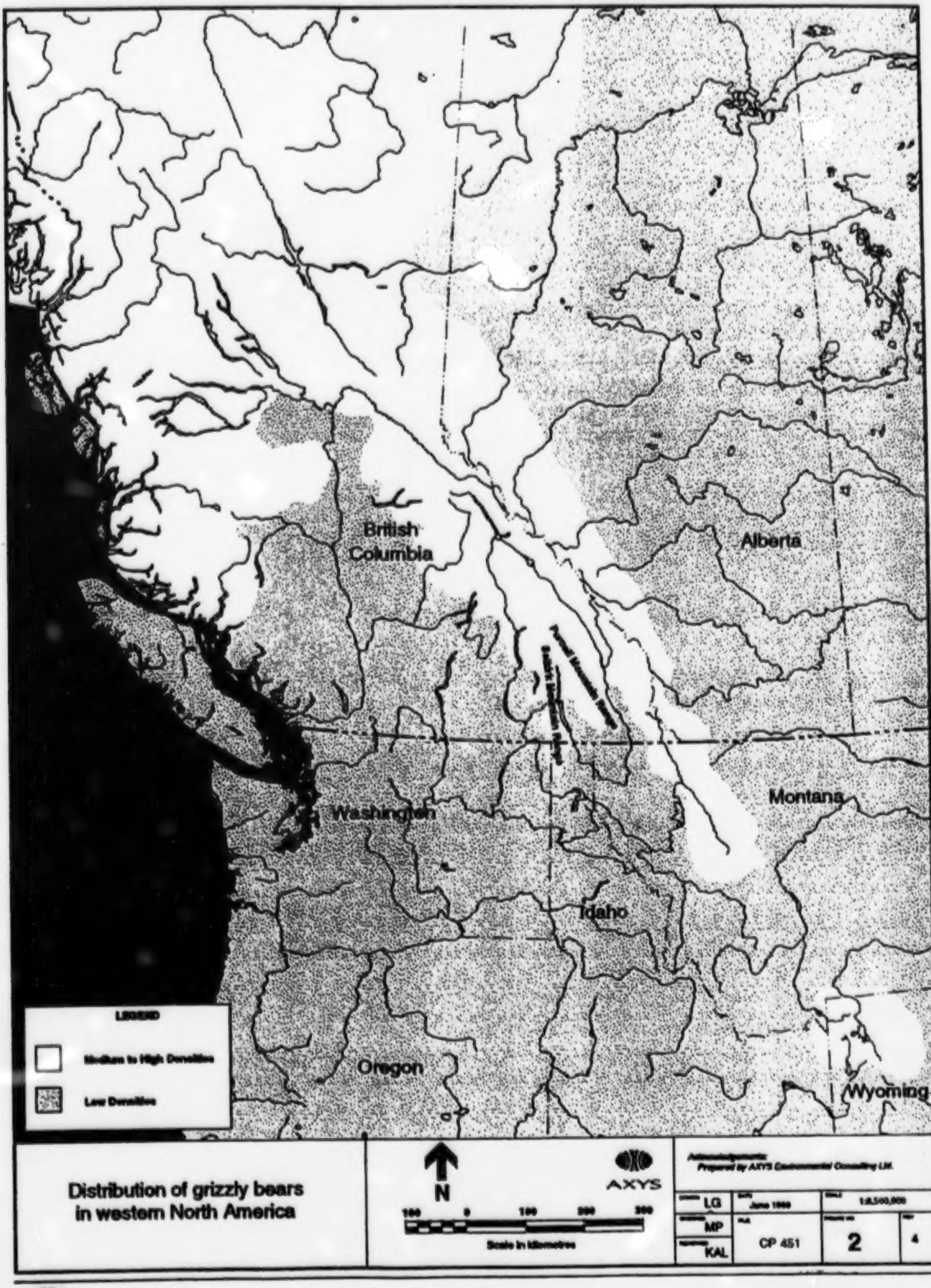
The average size of adult female home ranges from the West Slopes project (100% multi-annual, non-translocated) are 90 km^2 (range of 11-260 km^2) while adult males average 320 km^2. In the north fork of the Flathead watershed in southeast British Columbia, the average 95% multi-annual fixed kernal home range was 176 km^2 for adult females and 437 km^2 for adult males (F. Hovey, pers. comm.). In northwest Montana, Mace and Waller (1997) found average adult female home ranges to be 125 km^2 (range of 46-272) while adult males averaged 768 km^2 (range of 420-1114) using adaptive kernal methods.

2.2.3.2 *Grizzly Bear Population Status and Distribution in Southern British Columbia*

Currently within British Columbia, there are estimated to be approximately 10,000-13,000 grizzly bears (BC Environment 1995), or about half of the estimated Canadian population. Both provincial (BCMELP 1998) and federal (COSEWIC 1999) authorities consider the grizzly bear to be a Vulnerable species. Within British Columbia, grizzly bear population sizes have been estimated for Grizzly Bear Population Units (GBPU). Provincial GBPUs are areas of land used to manage grizzly bear populations and habitats. The 4,660 km^2 Central Purcell GBPU, which also overlaps most of the Central Purcell study area, has been estimated to contain 143 grizzly bears (M. Austin, pers. comm; B. Warkentin, pers. comm.). A portion of the 5,616 km2 North Purcells GPBU, which is estimated to contain 161 grizzly bears, overlaps the northwest corner of the Central Purcell study area, specifically the Glacier Creek basin.

At a finer resolution, grizzly bear populations in the southern interior of B.C. and western Alberta are also those that define the southern edges of continuously occupied habitat in North America (Figure 2) (McLellan 1998). The southern reaches of this occupied area include three "peninsular" grizzly populations in the Rocky, Purcell and the Selkirk mountain ranges representing the remaining relatively undisturbed suitable habitat in southeastern B.C. and southwestern Alberta (McLellan 1998). One of the province's goals in managing grizzly bear populations and habitats is to ensure that these peninsular populations are not allowed to incrementally diminish in size or distribution, thus potentially becoming "island" populations (McLellan 1998). Because island populations are by definition, isolated, they are demographically and genetically less resilient to the often negative effects of human activities that occur in areas surrounding the inhabited islands (Aune and Kasworm 1989; Primack 1995; Paquet *et al.* 1996). Local and regional extirpation and isolation of grizzly bear populations has occurred through many parts of the region south and southwest of the Central Purcell survey area (Banci 1990; USFWS 1993).

Figure 2. Distribution of grizzly bears in western North America



3.0 METHODS

To estimate grizzly bear numbers and explore patterns of distribution in the Central Purcell study area, DNA (Deoxyribonucleic acid) mark-recapture inventory methods were used (Resources Inventory Committee (RIC) 1998, Woods et al. *In Press*). The method is based on a systematic and repeated sampling of genetic tissue of grizzly bears and uses genetic markers to identify individual bears through microsatellite genotyping (a form of genetic or DNA fingerprinting). Capture histories are developed for all individuals. This capture history then forms the basis for a snapshot of the distribution of grizzly bears as well as a population estimate using mark-recapture techniques. The use of genetic markers also allows for parent-offspring relationships to be determined allowing a snapshot of natal dispersal throughout the study area. This technique is non-invasive and poses very little risk to the grizzly bears or inventory biologists. These procedures provide the best methods currently available for estimating bear numbers in largely forested areas without intensive trapping and radio collaring and the methods and results are replicable and scientifically defensible. The technique can not provide details of seasonal habitat use and habitat selection, home range and movements, reproductive rates of a population, mortality rates and causes of mortality within a population, nor does it capture all the animals in an area. Since its introduced in 1996 by Woods et al. (*In Press*), this DNA mark-recapture technique has been used to provide grizzly bear population estimates in British Columbia for three inventory projects in 1996 and five inventory projects in 1997.

The procedures, as described in the above mentioned documents, are described below to provide site and study-specific methods including a description of the study design, field methods, genetic analysis, DNA mark-recapture methods, and the resulting population estimation through application of computer programs CAPTURE (Otis *et al.* 1978) and MARK (White 1999).

3.1 Hair-Capture Sample Grid

A sample grid of 66 5-km x 5-km ($25km^2$) cells was established and overlayed onto the study region. The $25km^2$ size of each cell was chosen to increase the probability of capture of females that may have small home ranges (Banci 1991). Female home ranges in the West Slopes Bear Research Project, located 100 km to the north of this project, range from 11 to 160 km^2 (Woods et al. 1997).

Of the 66 potential cells, 62 were sampled (Figure 1, Appendix 1). Four cells were completely covered by glaciers and non-vegetated areas and therefore not sampled. Helicopters were used to access 52 (84%) cells while 10 were accessed by road. As grizzly bears live at relatively sparse densities, it was necessary to maximize the potential number of "captures" to ensure that there was adequate data available for statistical analysis. Therefore, hair-capture sites were placed in the best available and accessible grizzly bear habitat within each cell, including avalanche paths, riparian areas, sub-alpine zones, old logging cuts, passes, and travel routes.

3.2 Field Sampling Procedures

Hair-capture stations consisted of one strand of barbed wire that was hand tightened and stapled to the outside of trees forming a perimeter approximately 5 m away from the central bait,

and approximately 50 cm off the ground. The scent lure was hung between two trees within the barbed wire perimeter in burlap sacks approximately 4 m off of the ground at least 3 m from each tree. The scent lure consisted of approximately 5 kg of rotted meat and fat scraps (stored and rotted for one month in sealed 45 gal. drums), 250 ml of Alaska fish fertilizer, and 125 ml of rotted fish oil. Rotten meat was selected as a scent lure as bears may be searching for the carcasses of dead animals during the spring period (McLellan 1989a) and the smell of rotten meat acts as an attractant. To investigate the scent lure, the bear enters the wire perimeter and rubs against the wire leaving clumps of hair on the barbs. The bait was changed at every hair-collection visit, and the old bait was taken to a landfill and buried.

Sampling stations (1/cell) were established during 17–21 June 1998 and visited four times every 9 days from 27 June to 28 July (Table 1). The overall timing of the DNA survey coincides with the spring, and early summer pre-berry season when bears readily loose hair and the quality and distribution of habitat are relatively constant year to year. (Resources Inventory Committee (RIC) 1998). The early season is preferred because the spatial distribution of grizzly bears during the summer and fall varies with year to year variations in food supply (e.g. berries).

Table 1. Field schedule of site selection and hair collection from the 1998 grizzly bear survey in the Central Purcell Mountains of B.C.

		Hair collection session			
	Site establishment	1	2	3	4
Date	17–21 June	27–30 June	6–8 July	15–17 July	24–28 July

At each visit, the entire length of barbed wire was inspected, and hair samples (one sample is all the hairs from one barb on the wire) were collected and placed in individual envelopes, each marked with the sample site, date, and probable species. At the end of the day, samples were placed in sealed plastic bags, and stored in a freezer at -4°C until ready for analysis at the University of Alberta genetics lab.

3.3 DNA Analysis

3.3.1 Extraction

In the laboratory, each hair sample was examined under a microscope for the presence of hair roots. When a number of roots were present within a sample, six of the largest were selected for DNA extraction. The larger guard hairs were selected over the smaller under-fur hairs. The DNA was extracted using the Chelex-based protocol of Walsh *et al.* (1991). If re-extraction was required, the QIAGEN protocol (QIAGEN 1997) was used as it was determined to yield superior results.

3.3.2 Species Determination

Species identification was required for each hair sample because the hair-capture sampling stations readily attracted black bear (*Ursus americanus*) as well as grizzly bear. Mitochondrial DNA (mtDNA) was used to distinguish the species as outlined in Woods *et al.* (*in press*). Grizzly bears have a reliably consistent 15 base pair deletion relative to black bears at a particular locus on the mtDNA (Shields and Kocher 1991, Paetkau and Strobeck 1996). The target DNA of all samples was amplified using polymerase chain reaction (PCR) with oligonucleotide primers and run on an acrylamide gel and compared to samples of known species. Gels were run on an ABI 377 DNA Sequencer at Dr. Curtis Strobeck's population genetics laboratory at the University of Alberta. The ABI 377 sequencer was used to differentiate target DNA fragments of different length with the help of ABI Genotyper software. Species tests were attempted twice. If results were still inconclusive, DNA was re-extracted using the Qiagen protocol (QIAGEN 1997) and rerun as described above.

3.3.3 Genotyping (Identification of Individuals)

All grizzly bear samples were analyzed using microsatellites, (short [2–4] tandem repeat length polymorphisms) at six loci (G10A, G10B, G10C, G10D, G10L, G10Z) (Paetkau et al. 1995). A loci is a specific location on a chromosome and is characterized by having two alleles (a sequence of DNA) within each individual, one inherited from the mother and one from the father. Within a population of grizzly bears there is a certain amount of variability in the length of alleles at each locus (Paetkau et al. 1998). Individuals will have different combinations of allele pairs at the six loci, which has proven sufficient to distinguish individuals in several previous surveys in BC (Woods et al. 1997, Paetkau et al. 1998, Mowat and Strobeck *In Press*). Samples with different genotypes were considered to have originated from different individuals. The criteria used for accepting two samples coming from one individual is the probability of confusing two siblings as described in Woods et al. (*in press*). It is reasonably possible to sample siblings in a population, and therefore this probability was calculated based on the observed allele frequencies encountered in the population. Our standard was that there be a 95% probability that the two identical genotypes came from the same individual.

3.3.4 Gender Determination

After all of the individuals were identified, the best sample from each was used to determine the gender of each individual. This analysis is based on two consistently different alleles that occur on the sex chromosomes of many mammals. As females have two X chromosomes, they are homozygous (two identical copies of an allele) at this Amelogenin locus (Ennis and Gallagher 1994). Males, having an X and Y chromosome are heterozygous (having different alleles) at this locus.

3.3.5 Parent-Offspring Determination

Determining parent-offspring relationships is useful for examining patterns of familial linkages between watersheds and implications to natal dispersal throughout the study area. Microsatellites show Mendellian inheritance patterns and, therefore, may often be used to deduce parent-offspring relationships. Mothers will share one-half of their alleles across all loci with their offspring, as will fathers. Since age can not be determined from DNA, it is not possible

to determine which individual in a parent-offspring pair is the older one and therefore the parent. All cases presented are the result of exclusion of all other sampled individuals, i.e., the pairs of grizzly bears are the only possible options for parent-offspring dyads because no other individuals share one-half of their alleles with these individuals. While age is unknown, a mother-daughter relationship can be determined between pairs of females. However, between a male and female the relationship could either be a mother-son or father-daughter relationship.

3.3.6 Quality Control

Members of the study team have been involved in several surveys of grizzly bears using the DNA technique. During the course of this evolving technique, several quality control protocols were established. Species tests are attempted two times. If each attempt fails, samples of unknown species are then re-extracted and re-analyzed. All genotypes that only differed by one or two alleles were scrutinized and potentially re-analyzed to double-check the accuracy of the genotype. Any genotype that was suspicious for any reason was re-analyzed a final time, and excluded if the resolution was not satisfactory.

3.4 Population Estimation

After samples were assigned an identity it was possible to determine the capture history of each bear from the record of samples taken at each sample site on a particular date. These data were then used to describe the distribution of captured animals across the study area, and to generate a mark-recapture based population estimate.

There have been a variety of statistical software programs produced that provide mark-recapture population estimates from field data sets. The most noteworthy programs are program CAPTURE (Otis et al. 1978) and program MARK (White 1998). Program CAPTURE provides mark-recapture estimates of population size, as well as statistical tests to determine the most applicable model and corresponding estimator to the data. Program MARK is the most recent "state of the art" mark-recapture program. Program MARK's main strength is in the estimate of survival for population monitoring programs, however, it does provide population estimates for Jolly Seber mark-recapture models. As the primary purpose of the Central Purcell survey was to obtain estimates of the relative abundance of grizzly bears, program CAPTURE was used. A complete discussion of the assumptions used in CAPTURE is presented in Appendix 2.

Three issues influence the success of a mark-recapture project. The following is a summary of these three issues with a corresponding evaluation of the treatment of each issue by this study.

1. *Population closure*: Closure is the assumption that there are no births, deaths, immigration or emigration into the study area during the course of sampling. The results of statistical tests suggest that closure was violated during the course of sampling. The most probable source of this violation is bears leaving or entering the grid area during the study. This was most likely due to the size of the sampling area relative to the aggregate home ranges of all of the grizzly bears using portions of the study area. Therefore, the population estimate from this project should be considered to be "unbounded". An unbounded estimate includes the population of bears that reside within and around the mark-recapture sampling grid. This estimate cannot be used to calculate population density, but it does provide a biologically realistic estimate of the number of bears that use the Central Purcell Mountain Study Area.

Open Jolly Seber models were used to test for, and estimate, movement across grid borders. In addition, a detailed simulation study was conducted to determine closed model robustness to this type of closure violation.

2. *Sample size*: Sample size relates to the number of bears, and probabilities of capture for bears within the sampling area. In general, the sample size of bears obtained for the Central Purcell study was adequate for the use of mark-recapture models.

3. *Capture probability variation*: Program CAPTURE provides a set of tests that allow a quantitative assessment of how well the population meets the assumptions of mark-recapture models. Complex forms of capture probability were detected in the Central Purcell Mountain data set, which complicated the selection of mark-recapture models. A detailed simulation study was conducted to further determine the most appropriate model for this data set.

The unbounded population estimate was the result of a study design to look at grizzly bear distribution, develop an idea of how many grizzly bears use the Central Purcell Mountain Study Area, and provide base line data for a long term monitoring effort if required. While generating a population estimate was the primary goal in this survey, it was realized that a conventional estimate of density could not be generated due to the open nature of the study area and its small size in relation to typical grizzly bear home ranges. An "unbounded" population estimate such as that derived in this study provides a good estimate of the number of bears that used the Central Purcell Mountain Study Area during the sampling period. This may well be a more reasonable goal under any circumstance, as grizzly bears are difficult to census in forested habitat (Miller 1990, Mattson et al. 1996). The wide-ranging behavior of bears makes it difficult to assign a population estimate to a defined geographic area under the best of circumstances.

4.0 RESULTS

4.1 Capture Success

Hair-capture stations were active for four, ten-day sessions from June 17 through to July 28 1998, during which 1032 hair samples were collected. Two hundred sixty four samples were determined to be grizzly bears collected from 26 sites (Figure 3) and, from these samples, 33 individual grizzly bears were identified. The individuals included 18 females, 10 males, and five of unknown sex. The 33 individuals were captured a total of 63 times (Table 2), and 17 of the 33 bears were re-captured at least once (Table 3).

Thirteen sites captured only one individual grizzly bear while 12 sites had captured multiple individuals (one sample of grizzly bear hair could not be genotyped) (Figure 3). Eighteen bears were captured one time, 14 were captured two times, and one was captured three times. The sex classes of bears were pooled and analyzed separately in the population analysis and estimation, therefore, descriptive statistics are also presented for pooled and separate sex class data (Table 4).

Table 2. Numbers of grizzly bears identified by session and number of sample sites that produced hair samples in the Central Purcell grizzly bear population survey.

Session	1	2	3	4	Total
Number of grizzly bears identified	18	8	13	10	49
Cumulative number of grizzly bear hair captures [1]	24	9	19	11	63
Number of sites at which grizzly bear hairs were captured	17	7	12	7	na

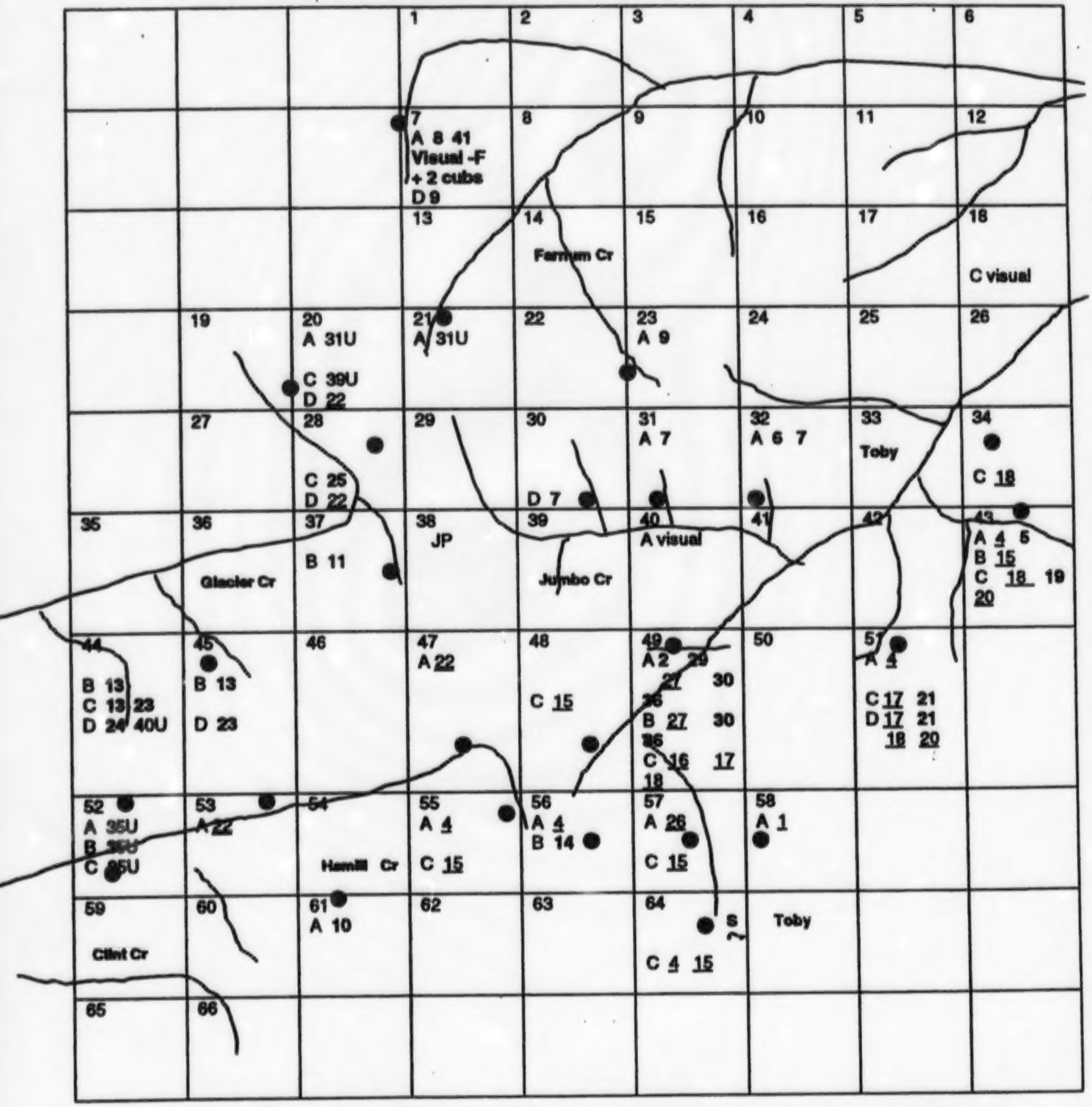
[1] includes repeated captures of individual bears within a session.

Table 3. Summary of captures and recaptures relevant to population estimate for the 1998 grizzly bear survey in the Central Purcell Mountains of B.C. [1]

Session	1	2	3	4	Total
Captures/session	18	8	13	10	49
New bears	18	4	9	2	33
Cumulative new bears	18	22	31	33	33
Recaptures from session 1		4	2	3	9
Recaptures from session 2			3	0	3
Recaptures from session 3				5	5
Total recaptures		4	5	8	17

[1] For the purposes of estimating the population only 1 capture per session for individual bears is included.

Figure 3. Schematic diagram of successful hair-capture sites for the 1998 Central Purcell Mountains Grizzly Bear Survey.



First number in upper left corner is Cell number; A, B, C, D, represents sampling session 1, 2, 3, 4, respectively; Bold numbers indicate females; Underlined numbers indicate male; U following number indicate unknown sex; Black circles represent grizzly bear capture locations within cell. JP = Jumbo Pass.

Table 4. Summary statistics of the 1998 grizzly bear survey in the Central Purcell Mountains of B.C.[1]

Session	1	2	3	4	Total
Males and females					
Animals caught	18	8	13	10	
Total caught	0	18	22	31	33
Newly caught	18	4	9	2	
Frequencies	18	14	1	0	
Females					
Animals caught	10	4	5	5	
Total caught	0	10	13	17	18
Newly caught	10	3	4	1	
Frequencies	12	6	0	0	
Males					
Animals caught	5	2	6	4	
Total caught	0	5	6	10	10
Newly caught	5	1	4	0	
Frequencies	3	7	0	0	

[1] "Animals caught" is simply the number of animals (marked and unmarked caught) in each sample. It is an index of the relative effectiveness of sampling efforts. The "Total caught" describes the number of marked animals in the population at the time of the sample session. The "Newly caught" describes the unmarked animals in each sample and indexes the overall effectiveness of the project in sampling the population. This number should progressively go down after each occasion if sampling is effective, as it does with this data set. The "Frequencies of capture" describes the number of times each bear identified or marked in the experiment was caught. As mentioned above, the genetic test for sex failed for five bears and therefore the number of males and females captured do not add up to the total number of bears. This problem will compromise the ability to analyze sex classes separately, but does not affect the overall population estimate.

4.2 Population Estimation

The results of statistical tests for capture probability variation and closure violation, as well as the results of simulation studies led to a population estimate of 45 grizzly bears in the Central Purcell study area (M_h (Chao); 95% Confidence interval: 37 to 68 bears) (see Appendix 2). This is the best estimate of the population of grizzly bears that were using the mark-recapture grid and surrounding area during the mark-recapture project.

The results of the model selection routine in program CAPTURE suggests that several factors affected capture probabilities including a behavioral response to capture, a natural difference in capture probabilities among individual bears (heterogeneity), and change in the population capture probability for each sample session (time) (see Appendix 2).

The results of simulation studies detailed in Appendix 2 and published studies on mark-recapture estimators (Otis *et al.* 1978; White *et al.* 1982; Pollock & Otto 1983; Boulanger and Krebs 1994) suggest that the M_h model and accompanying estimators are the most robust to sample biases present in the Central Purcell Survey data set. These findings are summarized below:

- Detailed simulation studies of estimator robustness to forms of capture probability variation present in the Central Purcell data set document a strong negative bias of population estimates with most mark-recapture estimators (i.e. they will tend to under estimate relative abundance). In comparison, the M_h (Chao) estimator (Chao 1989) exhibited a lesser degree of negative bias suggesting it is the most robust estimator available. In addition, the M_h (Chao) estimator displayed the highest degree of confidence interval coverage of all the estimators tested.

- The results of simulation studies suggest that the M_h (jackknife) estimator (Burnham and Overton 1979) may be the most robust to the seasonal effects of bears leaving (or entering) the study area. There is a good chance that bears do enter and leave the Central Purcell study area in response to seasonal changes in the distribution and abundance of their main food sources. The M_h (jackknife) estimator and M_h (Chao) estimators produced nearly identical estimates for the area of 46 and 45 bears respectively. However, published studies (Chao 1989), and the results of these simulations suggest that the confidence intervals generated for the Chao estimator are more consistent than the jackknife estimator and therefore this estimator was selected for this study.

- The assumption of heterogeneity of capture probabilities for individual bears may be the most biologically relevant for bears (B. McLellan pers. comm.). Given this, the M_h model and estimator that accounts for heterogeneity variation is biologically justified.

- An analysis with open Jolly Seber models in program MARK produced an estimate of 43.9 bears (confidence interval 33 to 84). The Jolly Seber model estimate is not robust to heterogeneity, and is less precise due to a higher degree of model complexity. However, it does estimate the amount of permanent movement across grid boundaries and, therefore, its estimate was also considered. The similarity of closed and open model population estimates further supports the estimate of 45 bears under a suite of model assumptions. Further discussion of open and closed population models and explanation of the estimation of population size are included in Appendix 2.

4.2.1 Population Closure

The Central Purcell Mountain study area is open to bear movements. Eight of the 33 grizzly bears (24%) were captured only once at the perimeter of the study area and it is likely that some portion of the home ranges of these bears lies outside the grid. For this reason the population estimate should be considered to be unbounded. Open mark-recapture models and simulation methods were used to further address the effects of population closure violation as further discussed in Appendix 2.

4.3 Capture Distribution

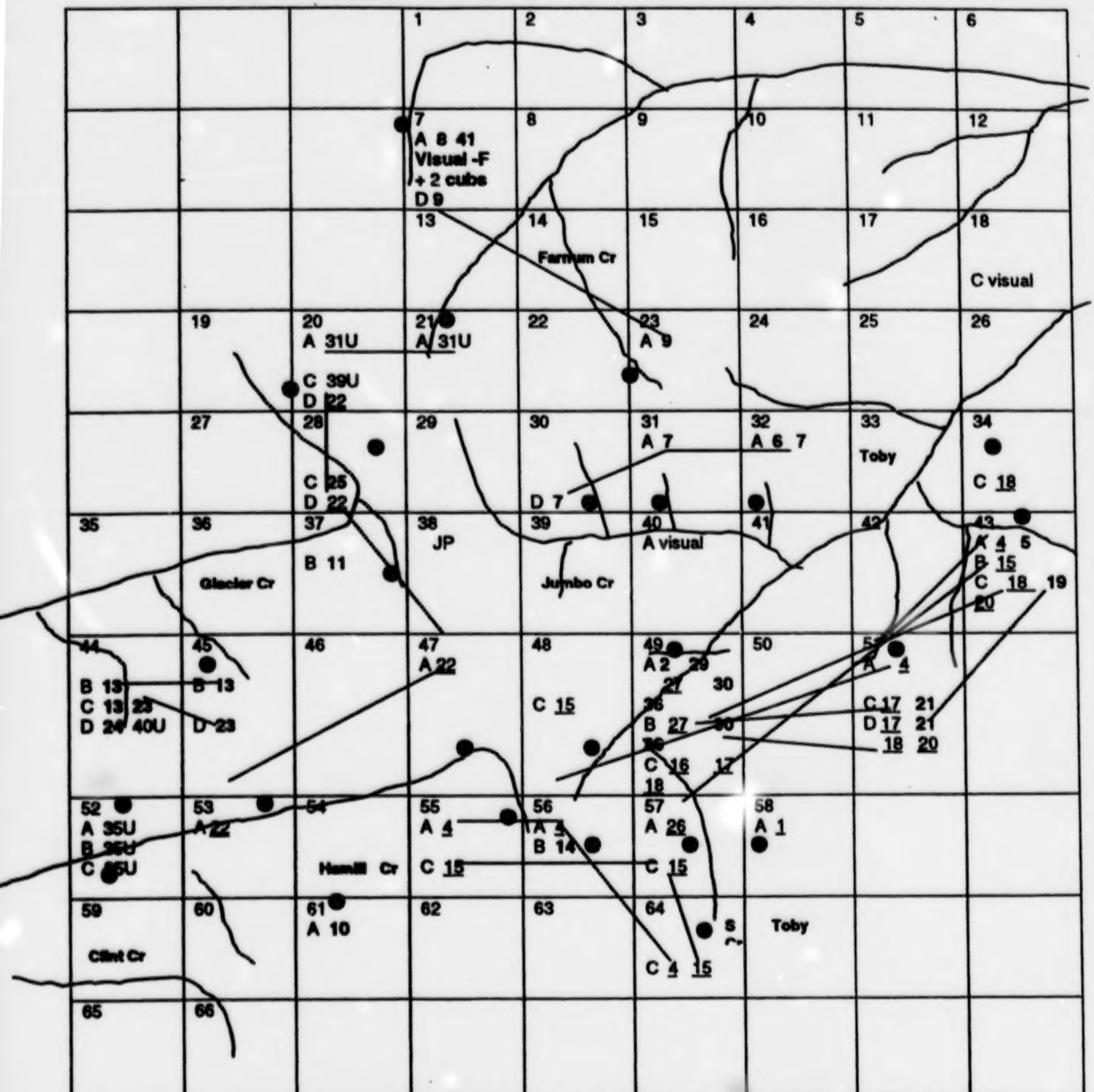
Grizzly bear hair samples were collected from all watersheds in the study area, with 26 of 62 cell sites having produced grizzly bear hairs (Figure 4). While capture results confirm the presence of grizzly bears within sample grid cells, the lack of capture results in other cells does not suggest the absence of grizzly bears from these cells or adjacent areas. Within the areas where grizzly bears were captured, females were more evenly distributed than were males (Figure 3, Table 5). Of the 18 female grizzly bears found in the Central Purcell study area, five were captured in the Glacier Creek watershed, three in Stockdale Creek, three in lower Toby Creek including Mineral and Coppercrown creeks, three in upper and south Toby Creek drainages, two in the Jumbo Creek watershed, and one female grizzly bear in each of Farnum and Hamill Creek watersheds (Table 5). While female captures were distributed throughout many watersheds, male captures were concentrated within those portions of the study grid that overlay the Purcell Wilderness Conservancy (i.e. Hamill, Upper Toby and South Toby Creeks) and the southern portion of the study area including Mineral and Coppercrown Creeks (Figure 3). While no male grizzly bears were captured in the Jumbo Creek watershed, this should not be misinterpreted to infer that males do not occur in Jumbo Creek valley. With successful captures, the design of the study allows insight into where grizzly bears do occur. Lack of captures, however, confirms just this and cannot be used to indicate where bears do not occur.

4.3.1 Capture Sites and Roads

Most grizzly bear captures were in the watersheds that had no roads at all or they were in the smaller, higher elevation, roadless feeder creeks associated with those watersheds where there are roads. Few grizzly bears were captured in sites located in the valley bottoms that have roads. For example, along the lower reaches of Toby Creek, most of the captures were along the tributary Mineral and Coppercrown creeks and captures in the Jumbo watershed were in the small spur valleys above the valley bottom along the middle and upper reaches of Jumbo Creek (see Figure 1).

The average distance from a main road for sites that captured grizzly bears was 6.2 km while the average for non-capture sites was 3.3 km (Chi-square, $p>0.25$). No grizzly bears were captured at sites within 1 km of a main road (Toby, Jumbo, Glacier and Horsethief Creek roads; n = 16 of 62 capture sites [26% of capture sites]). These are the main valley bottom gravel roads that are often used throughout the year by logging trucks, recreation and other vehicles.

Figure 4. Schematic diagram of successful recapture sites for the 1998 Central Purcell Mountains Grizzly Bear Survey.



First number in upper left corner is Cell number; Bold numbers indicate females; Underlined numbers indicate male; U following number indicate unknown sex; Black dots represent capture locations of grizzly bears; Green lines connect individual female grizzly bears recaptured at different locations ; Blue lines connect individual male grizzly bears recaptured at different locations; Purple lines connect grizzly bears of unknown sex recaptured at different locations.

Table 5. Grizzly bear captures by watershed in the 1998 grizzly bear survey in the Central Purcell Mountains of B.C.

Watershed	Number of individuals captured per watershed[1]		Approx. area of Watershed (km^2)
	Males	Females	
Jumbo	0	2	175
Upper Toby & South Toby	8	3	250
Lower Toby – Mineral, Coppercrown	5	3	225
Hamill	3	1	175
Glacier	1	5	250
Upper Horsethief and Farnum	1	1	125
Stockdale	0	3	75
Lower Horsethief	0	0	125
McDonald Creek	0	0	75
Law and Bruce creeks	0	0	75

[1] this represents individual bears captured per watershed. Because of movement between watersheds for both sexes, these numbers should not be confused with either the total numbers of male (10) and female bears (18) captured throughout the study area (see Section 4.1), nor the actual numbers of female and male bears that will use these watersheds from year to year. Both males and females will move among watersheds within and between years, and this dynamic state will inevitably lead to far greater numbers per watershed than is shown here.

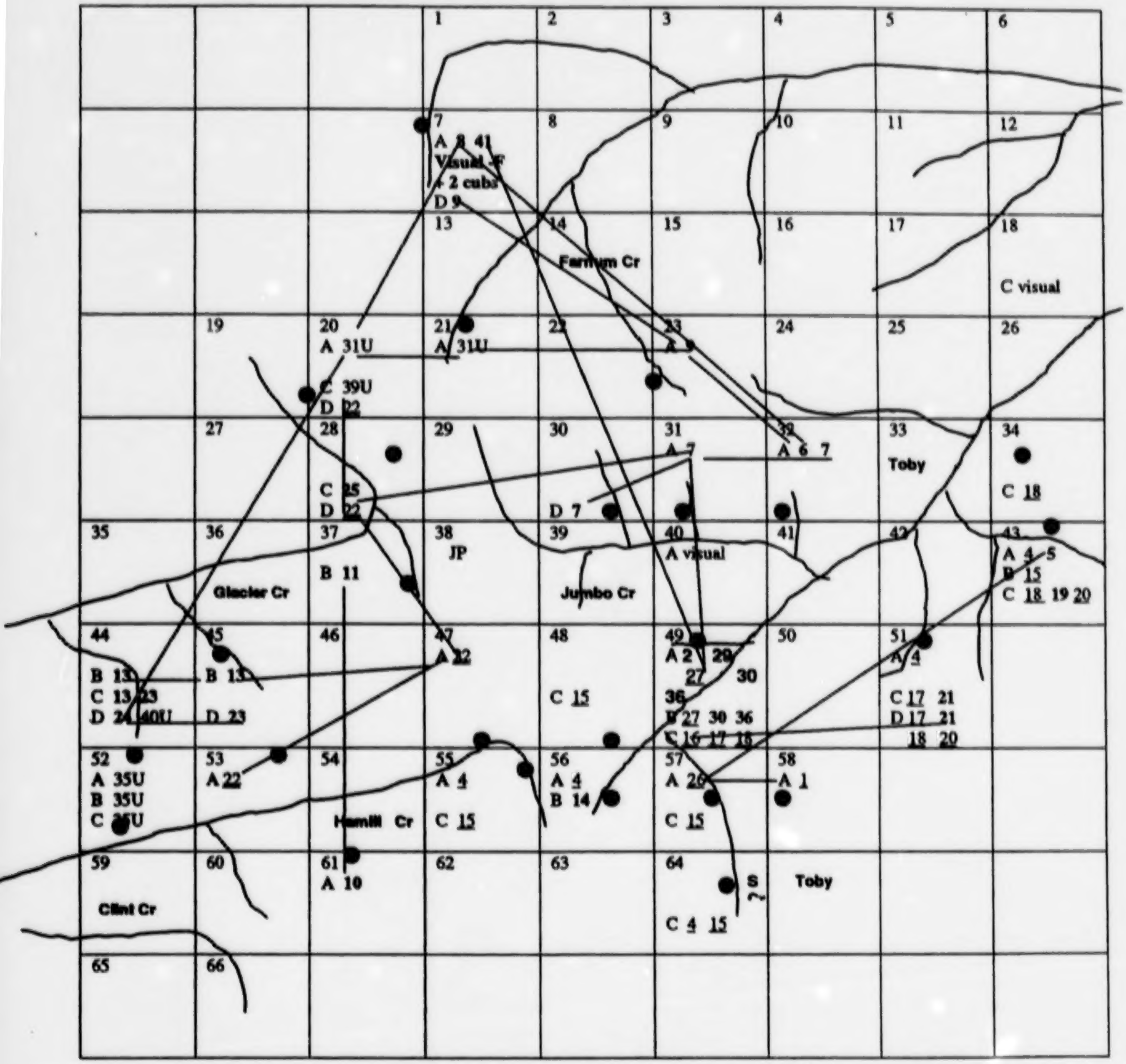
Table 6. Relationship between grizzly bear hair-capture sites and non hair-capture sites and the distance to all-season, gravel roads in the Central Purcell study area during 1998.

	Grizzly bear hair-capture sites	Non-hair-capture sites
Number of sites	26	36
Average distance to road per site	6.2 km (SE = 0.58)	3.3 km (SE = 0.82)
Range of distance to road from sites	1.8 – 17 km	0.3 – 12 km
Number of sites under 1.0 km from road	0	16

4.4 Parent-Offspring Relationships

Several pairs of bears were sampled that shared one-half of their alleles with each other suggesting that the pair represents a parent-offspring relationship (Figure 5). The relationships shown are individuals that probably no longer live and travel with their mother. Also, three sets of potential mother and cub relationships were detected in the groups captured in cells 49 and 51 (Figure 1). In Cell 49 (located in Pharaoh Creek in the Toby drainage) in sessions one and two, three bears consisting of two females (#30 and #36) and one male (#27) were captured. The mother is likely female #30 because she has a parent-offspring relationship with the other two individuals. Also, in session one we caught the pair #2 and #29 who share one-half of their alleles as do bears #17 and #21 caught in sessions 3 and 4 in Cell 51 (located in Coppercown Creek valley in the Toby drainage). The likelihood that the relationship is a mother and cubs is greater when all the family members are caught multiple times. As grizzly bears occupy overlapping home ranges (Mace and Waller 1997), the possibility also exists that these pairs are no longer together and are merely sharing habitats.

Figure 5. Schematic diagram of parent-offspring relationships for the 1998 Central Purcell Mountains Grizzly Bear Survey.



First number in upper left corner is Cell number; A, B, C, D, represent sampling session 1, 2, 3, 4 respectively; **Bold numbers indicate females**; Underlined numbers indicate male; U following number indicate unknown sex; Black circles represent grizzly bear capture locations within cell; Red lines indicate a parent-offspring relationship between the two individuals; Green lines connect recaptures of females having a parent-offspring relationship; Blue lines connect recaptures of males having a parent-offspring relationship.

5.0 DISCUSSION

The DNA capture technique used in this survey was first used on grizzly bears in 1995 and has since been used in several distribution and abundance studies. This is the first use of this technique as a survey tool used as the precursor to an environmental assessment in British Columbia.

5.1 Capture Success

A few trends are apparent from the summary capture statistics. First, almost half of the bears were recaptured during the course of sampling. This rate of recapture is higher than that observed in other inventory projects in British Columbia (J. Boulanger, unpublished data). Second, almost twice as many females were captured than males. This result should be interpreted cautiously because it was not possible to determine the sex from the hair samples of five of the grizzlies in the capture sample (15% of all individuals). The ratio of males to females observed in this study (0.56) is similar to the ratio observed from the West Slopes Project in 1997 (0.57) on the east side of their study area. However, in 1998, the West Slopes Project recorded a male to female ratio of 1.5 on the west side of their study area. In both years they used a similar study design to that used in the Central Purcell survey. At this point, it should be noted that it is difficult to determine whether observed ratios of sex classes are of biological significance or are artifacts of sampling design and thus should be interpreted cautiously.

One noteworthy point is that the population estimates from this data set are only slightly larger than the actual number of grizzly bears caught (33 of an estimated 45 grizzly bears, see Section 3.4 and Appendix 2). This suggests that sampling was effective in documenting the seasonal distribution of grizzly bears across the sampling grid.

5.2 Population Estimate

An unbounded population of 45 grizzly bears was estimated to occur in the Central Purcell study area. A conventional estimate of the density of the grizzly bear population could not be generated due primarily to the open nature of the study area and also to the study area's small size (1650 km^2) in relation to typical grizzly bear home ranges. An "unbounded" population estimate such as that derived in this study provides a good estimate of the number of bears that used the area during the sampling period. This well may be a more reasonable goal under any circumstance, as grizzly bears are generally difficult to census in forested habitat (Miller 1990; Mattson *et al.* 1996). The wide-ranging behavior of bears makes it difficult to assign a population estimate to a defined geographic area under the best of circumstances. Furthermore, the advanced survey techniques that have been made possible as a result of DNA fingerprinting probably provide a more accurate idea of the number of bears that could be affected in the area of a proposed development than was possible with the techniques that were available in previous decades.

The open geographic nature of the Central Purcell study area precluded an accurate estimation of grizzly bear population density, thus somewhat limiting the basis with which to compare results to similarly conducted population surveys. However, in the absence of an accurate estimation of population density, the ratio of number of animals to unbounded study area size can cautiously be used to compare results of the Central Purcell survey to those generated from

studies in similar ecosystems in southwestern and south-central British Columbia. The ratio of 2.7 bears/100km2 in the Central Purcell study area is comparable to results of surveys from both the West Slopes study (104 grizzly bears in the 4096 km^2 study area and a ratio of 2.5 grizzly bears/100 km^2 [Woods *et al. In Press*]) and the Central Selkirk study (258 grizzly bears in a 9,866km^2 study area and a ratio of 2.6 grizzly bears/100 km^2 [Mowat and Strobeck *In Press*]). These studies are in relatively similar ecosystems, however the methodology of the Selkirk study used a very different sampling design and therefore the estimates from these projects should be compared with great caution.

5.2.1 Population Closure

The study area is open to bear movements. Eight of the grizzlies were captured only once at the perimeter of the study area and it is likely that some portion of the home ranges of these bears lies outside the grid. Movement in and out of the study area is likely to occur in all directions. The characteristic topography in the region, specifically the presence and orientation of very high rugged mountains and incised valleys, likely has a marked influence on movements of grizzly bears to and from the study area. North-south movements are likely promoted by what appears to be presence and good distribution of suitable habitat for grizzly bears both north and south of the study area. North-south movements through the study area are likely somewhat restricted in the area between Starbird and Commander glaciers due to the restrictively high and rugged terrain. East-west movement is possible due to the open eastern and western boundaries. Limitations on east-west movement in and out of study area may be limited by the presence of diminishing grizzly bear habitat quality on the eastern bounds of the study area, and by coinciding increases in human-caused habitat displacement, particularly on the eastern study area periphery.

5.2.2 Capture Session Variability

The first collection session captured 18 individual grizzly bears. Captures in sessions two, three and four decreased to 8, 13, and 10 captures, respectively. There are several possible explanations for this reduction in capture rate. The first collection session began on June 17, 1998, but it would have been useful to begin work by late May or early June. The spring of 1998 came relatively early, and the snow was gone from the study area by late May. The progression of the seasons and the onset of the summer berry crop was also early as berries were already ripening by sessions three and four. As the study area appears to lack significant berry patches within its boundaries, grizzly bears probably do not travel into the study area in significant numbers to seek berries in the late summer and some bears may travel out of the area at this time to seek berries. Hence, capture success may have decreased over time due to the combined result of the early spring in 1998 and the possible limited extents of late summer (berry season) habitat within the study area compared to areas outside the study area.

A second consideration relates to heavy rains that occurred during sessions two and three, which may have reduced the effectiveness of baits in attracting bears. Bait drags were used to draw bears from the open feeding areas over to trees where the stations were located, but heavy rain may have reduced the attractive qualities of the scent lures and some bears may not have detected the baits because of the effects of the rain.

Another possibility for the variation in the captures is a behavioral response by the bears to not receiving a "food reward" at the sampling station and thus dissuading the bear from returning to the station in subsequent sessions. While this may occur, the data shows that there was a

relatively high rate of recapture for many individuals and, therefore, this particular behavioural effect was probably minimal.

Lastly, individual bear behaviour and dynamics involved in foraging habitat selection may also have had some influence on capture variation through the sampling sessions. Feeding areas and/or movement corridors were targeted for sampling station placement. However, it must be considered that the bears could have used feeding areas other than those chosen for sampling stations within the study area. The effect of this problem on bias of estimates was minimized as by having relatively small cell sizes (25 km2) that help maximize the probability of captures of bears in the population. These points are raised not to suggest that the results of this study are not reliable, but to explore the reasons behind the differences in capture success between sessions (see Appendix 2 for a detailed discussion of capture probability variation and its effects on population estimates).

5.3 Distribution of Grizzly Bears

The results of this study indicate that the distribution of bears across the study area was not uniform. This compares to similar distributions of grizzly bears from results of DNA fingerprinting surveys in the West Slopes and in the north and the Central Selkirks (Woods *et al.* 1997; Mowat and Strobeck *In Press*). The non-uniform distribution of grizzly bear captures in the Central Purcell survey is, in part, a likely attribute to varying distribution of quality grizzly bear habitats in the study area. The majority of bears were captured in the southern one-third of the study area (i.e., Toby, Hamill and Glacier drainages) and most of these were males. As adult male grizzly bears have been known to usurp higher quality, secure habitats compared to other cohorts (Mattson *et al.* 1987; McLellan and Shackleton 1988), the distribution of male captures may indicate that relatively high quality, secure foraging habitats occur in greater concentration in the southern portions of the study area. Alternatively, fewer male captures in the north may be an artifact of higher road density in the north and the associated possibility that greater road access has led to increased hunting and increased harvest of male bears from these northern valleys. During the course of the survey, anecdotal records and observations by field biologists indicated that the southern valleys contained fewer roads and apparently higher quality habitat than some of the more northern and eastern drainage valleys. Most notably, with the exception of a few lush riparian areas (cells 4 and 5), overall habitat quality in the lower and middle and lower Horsethief Creek valley appeared to be relatively drier and more heavily forested than southern, central and western portions of the study area. In the lower and middle Horsethief Creek valley, there were no grizzly bears captured. This result, to note, should be interpreted with caution and not interpreted as being necessarily indicative of grizzly bear absence from the lower and middle Horsethief Creek valley. The survey was essentially a one-season "snapshot" of bear habitat use and in the northeast of the study area, where bear habitat appears to be of generally lesser quality, grizzly bears may nonetheless occur but show increased avoidance to the relatively higher levels of human activity. Grizzly bears may also occur in side drainages off of the main Horsethief Creek such as McDonald, Bruce and Law creeks where apparently suitable spring and early summer habitat was in evidence.

In those portions of the study area in which grizzly bears were captured, there was a fairly even distribution of female captures. As in the West Slopes study (Woods *et al.* 1997), this survey found 1-3 female bears in drainages in which bears were captured. Of the 18 total female grizzly bears captured, five were from the Glacier Creek valley, three along upper and south Toby Creek, three along lower Toby Creek including Coppecrown and Mineral creeks, three

along Stockdale Creek, two in the Jumbo Creek valley, and one each in Farnum/upper Horsethief and Hamill Creek valleys. These result indicates that the critical female component of the Central Purcell population requires and uses habitats that are distributed throughout the landscape. In the Jumbo Creek valley, an acknowledged focal point to the Central Purcell survey, the capture of two unrelated female bears confirms the presence of the minimum of two potential grizzly bear family units in this valley. The two females captured in Jumbo valley have close relatives (parent-offspring) located in adjacent watersheds to the north and south (see Figure 5), confirming grizzly bear dispersal and use of habitats in and around Jumbo valley and potentially also other basins in the study area.

5.3.1 Capture Sites and Roads

From past research, it is known that some grizzly bears show avoidance of habitats near human activity and roads, while others adapt or are compelled to use habitats near human activity during certain parts of the year (Archibald *et al.* 1987; Mattson *et al.* 1987; McLellan and Shackleton 1988; Kasworm and Manley 1990; Gibeau *et al.* 1996; Mace *et al.* 1996). While the Central Purcell survey resulted in most captures occurring at sites located away from valley bottom roads, and certain sites near roads such as the lower Toby and Jumbo Creek roads produced no hair samples, it is difficult to make conclusions from the data about either grizzly bear preference or avoidance of habitat near roads.

Several possible reasons exist that may explain the absence of successful captures from specific sites near roads. Some bears may actually be using habitats near roads but have become wary of contact with humans and, thus, may have avoided trap sites with evident sign of human activity. Alternatively, bears may be using these roadside habitats in other seasons (outside of our spring sampling season) or simply avoiding use of habitat near roads. Other intrinsic factors come into play as well. Population density and behavioural dynamics also influence the way in which bears use habitats.

While there are several possible reasons for varying distributions of successful hair captures, there are also functional aspects of the Central Purcell survey that limit the potential to test hypotheses and derive conclusions on grizzly bear habitat use near roads in the area. First, the survey was essentially a "snapshot" in time. Attempts to accurately make conclusions about a species' general ecology and relations to human activity in a given area from a single season of data are limited. Second, while results of the survey provide information on habitats that bears were using when captured, they do not provide information on bear preference, lack of preference or avoidance of habitats or areas near human activity. Such information could be obtained from longer-term studies of radio-collared animals.

Hence, the results of the Central Purcell survey show wide distribution of grizzly bears in the Central Purcells study area. While some of the data might suggest that grizzly bears avoid habitats near roads (i.e, capture sites near roads that produced no grizzly hair samples) and other data the opposite (i.e., parent-offspring relationship data showing closely related bears occurring on opposite sides of roaded valley), the inherent nature of the study is such that the resulting data does not allow objective insight into whether or not bears are avoiding habitats near roads. In the context of future assessment of potential effects of human activity and development on grizzly bears, it is advisable that the results of the Central Purcell survey be used cautiously while also considering results from pertinent, long-term studies of radio-collared grizzly bears that have been conducted in other mountain ecosystems.

5.3.2 Grizzly Bear Home Range

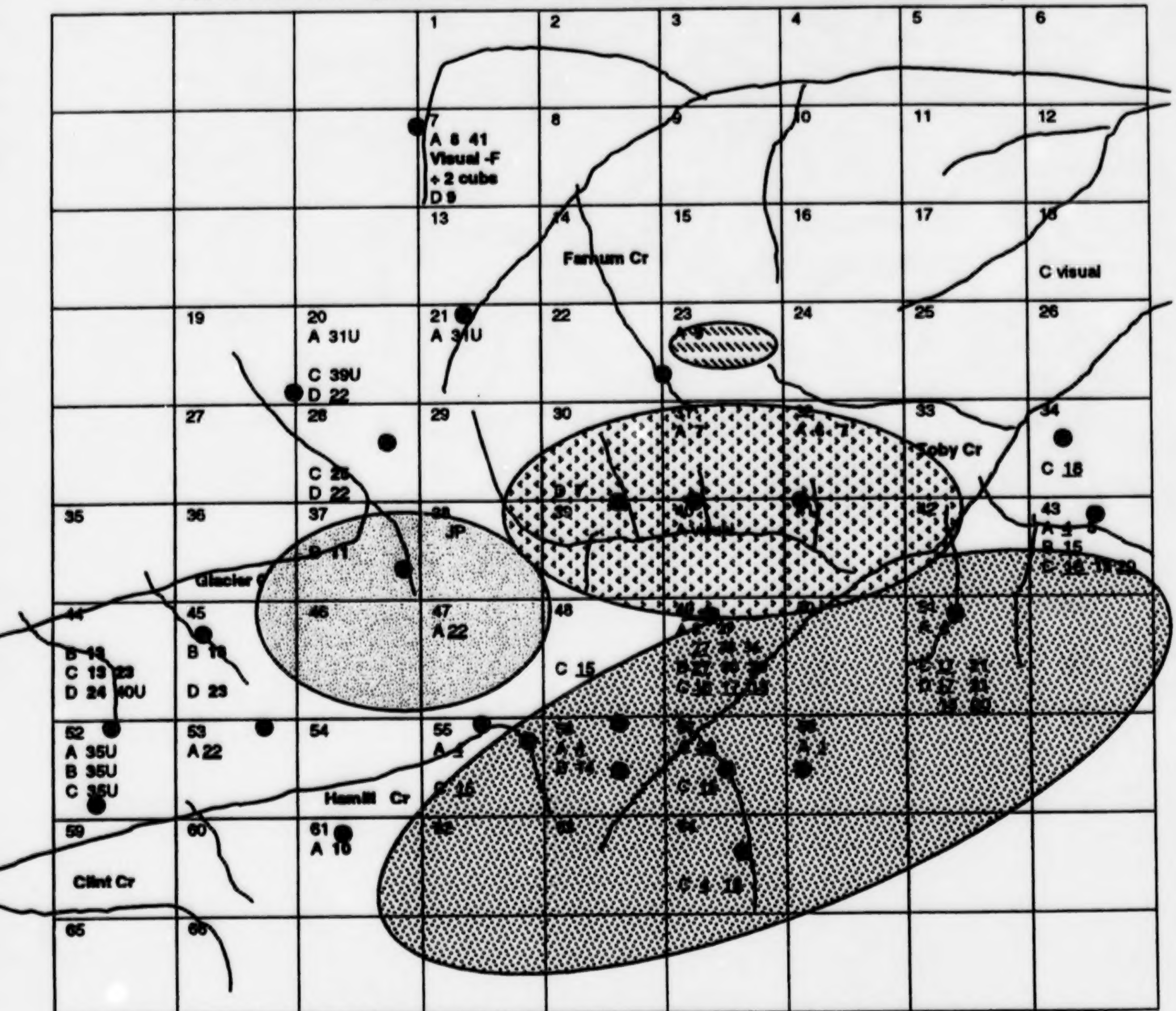
The data gathered from the Central Purcell study area provides a six week snapshot of bear distribution in the study area, and thus is not appropriate to determine annual home ranges. However, multiple capture data (recaptures) did allow for a glimpse into spring and early-summer home ranges within this specific year for specific bears. As these recaptures correspond to movements that occurred over a six-week period, the annual and lifetime home ranges will likely be much larger.

The shape of individual home ranges will vary most according to the underlying distribution of suitable habitats. Grizzly bears are not territorial and their home ranges often overlap with other bears of both sexes (Mace and Waller 1997). Actual home range data for grizzly bears in the West Slopes (Woods *et al.* 1997) was used to interpolate and estimate potential sizes of seasonal home ranges that may be expected for grizzly bears in the Central Purcell study area (Figure 6). The West Slopes study area is less than 100 km to the north of the Central Purcell study area and similar ecological characteristics are evident in the two study areas. The average home range of female bears in the West Slopes was 90 km^2 (11–160km^2), and the average home range for males was 320 km^2 (Woods *et al.* 1997). In the Central Purcell study, several bears were captured at a series of locations (for example, male #15 and female #7 in Figure 4) that suggest that their seasonal home ranges may be similar to the average home ranges found in the West Slopes study area (see Figure 6).

5.4 Proposed Project Assessment Recommendations

The results of the Central Purcell grizzly bear survey confirm the presence of a functioning grizzly bear population in the Purcell Mountains of southcentral British Columbia. It also confirms the presence of several female grizzly bears occurring within a home range diameter of the location of the proposed Jumbo Resort development. Following on the findings of this study, a comprehensive assessment of the potential effects on grizzly bear populations of the proposed Jumbo Resort Project development must firstly entail thorough investigation of potential direct project effects. This would include assessment of effects of direct habitat loss, habitat alienation and displacement of grizzly bears from habitats, increased fragmentation of habitats and movement corridors, and potential mortalities to female and male grizzly bears that occupy local habitats in around the Jumbo Creek valley. In addition to effects attributed directly to the project, potential project-induced effects and their potential significance on grizzly bear populations must also be examined. Finally, the manner and significance which direct and induced project effects may combine with effects of past and/or ongoing human impacts on local and regional grizzly bears must also be addressed. In essence, estimation of the significance of the potential direct, induced and cumulative impacts of the proposed Jumbo project development on regional grizzly bear populations must be made from within the context of relevant temporal and spatial scales, full knowledge of past and proposed human activities in the region, and from the position of comprehensive knowledge on grizzly bear population science and effectiveness of human impact management.

Figure 6. Schematic diagram of average hypothetical home ranges for female and male grizzly bears for the 1998 Central Purcell Mountains Grizzly Bear Survey. Home ranges are based on home range data from the West Slopes Project (Woods *et al.* 1997).



1st number in upper left corner is Cell number; A, B, C, D, represent sampling session 1, 2, 3, 4 respectively; **Bold numbers indicate females**; <u>Underlined numbers indicate male</u>; U following number indicate unknown sex

Average female home range in the Upper Columbia ecosystem (West Slope Bear Research Project) – 90 km^2

Upper range of female home ranges – 166 km^2

Lower range of female home ranges – 11 km^2

Average male home range in the Upper Columbia – 320 km^2

5.5 Effectiveness of Monitoring

The precision attained in this effort suggests that the DNA survey method has the potential to provide a long term monitoring function. The DNA technique is reliable and relatively non-intrusive, however, the power to detect incremental changes in population numbers over relatively short periods of time (e.g. < 10 years) is limited. The power analysis techniques that are reviewed in Appendix 2 require at least six annual, consecutive DNA surveys at a similar survey intensity to this study to detect a 35 percent change in the relative abundance of grizzly bears, using regression based methods. Hence, the resolution offered by this technique will only detect general changes in relative abundance and distribution. Therefore, while monitoring provides a tool, it is only one of several that are required for the effective management of grizzly bears and grizzly bear habitat. It is recommended that a more detailed study of population monitoring strategies using open models and program MARK be conducted if a monitoring program is to be implemented.

6.0 CONCLUSIONS

Primary results of the survey include the following:

1. The unbounded population estimate for the Central Purcell study area and surrounding area was 45 grizzly bears with a 95 percent confidence interval of 39 – 64 grizzly bears.

2. 33 individual bears were identified from the hair samples including 18 females, 10 males, and 5 of unknown sex. Approximately ½ of the bears were recaptured at least once.

3. There was a non-uniform distribution of grizzly bear captures within the study area.

4. Grizzly bears were sampled throughout the study area; distribution of captures was non-uniform with least success obtained in the lower and middle Horsethief Creek valley in the northeastern quadrant of the study area.

5. Female captures were relatively evenly distributed in those drainages where grizzly bear presence was confirmed. Of the 18 female grizzly bears found in the Central Purcell study area, five were captured in the Glacier Creek watershed, three in Stockdale Creek, three in lower Toby Creek including Mineral and Coppercrown creeks, three in upper and south Toby Creek drainages, two in the Jumbo Creek watershed, and one female grizzly bear in each of Farnum and Hamill Creek watersheds. The two female grizzly bears captured in the Jumbo valley confirm that a minimum of two female grizzly bears use habitats in the Jumbo Valley. Both male and female grizzly bears move among these drainages.

6. The majority of male grizzly bears were sampled from within the southern one third of the study area.

7. The study area is not closed to grizzly bear movements, suggesting that bears were leaving or entering the study area during the sampling period.

8. Many of the bears in adjacent watersheds in the study area are related to each other.

9. The majority of captures in the watersheds that had roads occurred in the side, non-road drainages. Grizzly bears were not captured within 1 km of main valley bottom roads, even though 26% of the capture sites were located near these roads. This result, however, neither confirms not refutes grizzly bear use of habitat near roads in the study area. Use of roadside habitat is considered dependent on individual bear behaviour, habitat conditions and population characteristics and densities in the affected region.

10. This survey shows that there is a currently viable resident population of grizzly bears occupying the Central Purcell study area. History and extrapolation from other research efforts in the region suggest that there will be impacts associated with the development, but further assessment will be required to attempt to quantify and estimate the significance of those impacts.

The proposed project and its associated access has the potential to locally reduce habitat availability for bears, impede regional grizzly bear movements , and directly or indirectly affect long term grizzly bear populations in and around the Central Purcell study area. The magnitude and significance of these effects would depend on the results of individual and cumulative

effects from project development and operations, the effects of human activities indirectly associated with the project ("spin-off" activities), and the effects of past future human activities that have no direct or indirect relation to the project but that are nonetheless pertinent to an assessment of grizzly bear habitat and population conservation. Grizzly bears and grizzly bear populations have long been impacted negatively from human activities and developments that often result in habitat degradation, fragmentation and direct and indirect deaths of bears (Mattson 1990). Due mainly to the species' vast home ranges and seasonal and annual movement patterns, there is a proclivity for this species to encounter widely dispersed human activities. Hence, what may appear to be localized impacts can also have implications for regional populations as several individuals within populations may encounter and suffer negative consequences from one or more human activities and developments within overlapping home ranges. Likely effects of developments are considered most severe when affecting female grizzly bears, the essential reproductive segment of the population. The ability of a grizzly bear population to withstand potential negative impacts of human activity and to recover from reductions in populations are exacerbated by the species' generally low demographic resilience (i.e., low reproductive capacity, late sexual maturity, low population densities and general intolerance of much human activity) (Weaver *et al.* 1996). Results of the Central Purcell Grizzly Bear Survey confirm the presence of a currently viable population of grizzly bears in the Central Purcell study area, which encompasses the location of the proposed Jumbo Glacier Resort Development. History and extrapolation from research and assessment efforts suggest that there will be impacts associated with the development, but further assessment will be required to attempt to quantify and estimate the significance of those impacts.

7.0 ACKNOWLEDGEMENTS

Kirk Strom of AXYS Environmental Consulting Ltd. was responsible for study design and project coordination, oversaw the field program, and contributed to and edited the final report. Michael Proctor, a biology graduate student at the University of Calgary, was responsible for extraction and testing of DNA samples, assisted with study design, was significantly involved in field work and also made contributions to the final report. John Boulanger, of Integrated Ecological Research, modeled the DNA capture data, established population estimates, prepared Appendix 2 on population modeling, and also contributed to the final report.

Dr. Curtis Strobeck of the University of Alberta is gratefully acknowledged for his provision of laboratory facilities for DNA analyses.

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Darren Bennett (AXYS) prepared sections of the Introduction and background literature review. Kevin Lloyd, Glenn Letham and Lindsay Giles (AXYS) produced Figure 1. Michael Proctor, Kevin Lloyd and Lindsay Giles produced Figure 2. Kevin Lloyd (AXYS) provided technical and editorial recommendations on the final report.

Dr. Bruce McLellan (BC Ministry of Forests) reviewed the study protocol, visited the study site to ensure adherence to the methodology and reviewed and provided critique on report drafts. Matt Austin (BC Ministry of Environment, Lands and Parks) also provided critical appraisal of draft reports. A permit to establish sampling stations and conduct sampling in the Purcell Wildlife Conservancy section of the project area was granted by Wayne Stetski, District Manager, and Mike Gall, BC Parks – Kootenay District, to AXYS Environmental Consulting Ltd.

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APPENDIX 1

Appendix 1. Grizzly bear hair-capture site description for the 1998 Central Purcell Mountains grizzly bear study.

Site #	Drainage	Creek	1:50,000 Map no.	Elev. (ft.)	BGCZ Unit Zone	BGCZ Unit Subzone	Comments	Access
1	Horsethief	Stockdale	82K/10	5200	ESSF	dk	AV path - Rip	heli
2	Horsethief	Stockdale	82K/10	4660	ESSF	dk	Riparian near AV	heli
3	Horsethief	Horsethief	82K/9	4250	MS	dk	Riparian - spruce	heli
4	Horsethief	Horsethief	82K/9	4260	MS	dk	Old cut	heli
5	Horsethief	Horsethief	82K/9	3620	MS	dk	Rip - wetland	heli
6	Horsethief	Horsethief	82K/9	5760	MS	dk	AV path	heli
7	Horsethief	Stockdale	82K/10	6220	ESSF	dk	AV path - Rip	heli
8	Horsethief	Horsethief	82K/10	4440	ESSF	dk	AV path - Aspen	road
9	Horsethief	McDonald	82K/9	5380	ESSF	dk	AV path - Rip	heli
10	Horsethief	Gopher	82K/9	5820	ESSF	dk	Old cut	heli
11	Horsethief	Law	82K/9	6660	ESSF	dk	AV path	heli
12	Horsethief	Bruce	82K/9	5900	ESSF	dk	AV path	heli
13	Horsethief	Horsethief	82K/7	4760	ESSF	dk	AV path - rip	road
14	Horsethief	Horsethief	82K/10	4820	ESSF	dk	AV path - Aspen	road
15	Horsethief	McDonald	82K/8	6220	ESSF	dk	AV path	heli
17	Horsethief	Bruce	82K/8	6260	ESSF	dk	AV path - ESSF	heli
18	Toby	Spring	82K/8	7100	ESSF	dk	AV path - larch	road
19	Glacier	NF Glacier	82K/7	5840	ESSF	wm	sub-alpine	heli
20	Glacier	Starbird P	82K/7	6120	ESSF	wm	AV path	heli
21	Horsethief	Horsethief	82K/7	5420	ESSF	dk	AV path - Rip	heli
22	Horsethief	Farnham	82K/7	5360	ESSF	dk	AV path - Rip	heli
23	Horsethief	Farnham	82K/7	5900	ESSF	dk	AV path	heli

			1:50,000	Elev.	BGCZ Unit			
Site #	Drainage	Creek	Map no.	(ft.)	Zone	Subzone	Comments	Access
24	Toby	Delphine	82K/8	5140	ESSF	dk	AV path	heli
25	Toby	Clearwater	82K/8	6300	ESSF	dk	AV path	heli
26	Toby	Toby	82K/8	4300	MS	dk	Av path - rip	road
27	Glacier	NF Glacier	82K/7	5180	ICH	mw2	AV path - Rip	road
28	Glacier	NF Glacier - Monica M	82K/7	6400	ESSF	wm	Rip - ESSF	road
29	Toby	Jumbo	82K/7	5600	ESSF	dk	AV path - Rip	heli
30	Toby	Jumbo	82K/7	5640	ESSF	dk	AV path	heli
31	Toby	Jumbo	82K/8	6380	ESSF	dk	AV path	heli
32	Toby	Jumbo	82K/8	6740	ESSF	dk	AV path	heli
33	Toby	Toby	82K/8	4040	MS	dk	Av path - Rip	road
34	Toby	Barbour	82K/8	5540	ESSF	dk	AV path	heli
35	Glacier	Birnam	82K/7	4650	ICH	mw2	Riparian - wetland	heli
36	Glacier	Glacier	82K/7	4280	ICH	mw2	AV path	road
37	Glacier	SF Glacier	82K/7	5540	ESSF	wm	AV path	heli
38	Toby	Jumbo	82K/7	5700	ESSF	dk	AV path	heli
39	Toby	Jumbo	82K/7	5480	ESSF	wm	AV path	heli
40	Toby	Jumbo	82K/8	4700	MS	dk	Av path - regen	road
41	Toby	Jumbo	82K/8	4540	MS	dk	AV path	heli
42	Toby	Toby	82K/8	4460	MS	dk	Av path	road
43	Toby	Mineral	82K/8	5940	ESSF	dk	AV path	heli
44	Glacier	McLeod	82K/7	6900	ESSF	wmp	sub-alpine - open	heli
45	Glacier	Glacier	82K/7	5700	ICH	mw2	AV path	heli
47	Hamill	Hamill	82K/7	4760	ICH	mw2	Riparian - wetland	heli

Site #	Drainage	Creek	1:50,000 Map no.	Elev. (ft.)	BGCZ Unit Zone	BGCZ Unit Subzone	Comments	Access
48	Toby	Toby	82K/7	5580	ESSF	dk	AV path	heli
49	Toby	Pharaoh	82K/8	5320	ESSF	dk	AV path	heli
50	Toby	Stark	82K/8	7060	ESSF	dk	AV path	heli
51	Toby	Coppercrown	82K/8	5820	ESSF	dk	AV path	heli
52	Glacier	Hamill	82K/7	3480	ICH	mw2	AV path - ICH	heli
53	Hamill	Hamill	82K/7	5800	ESSF	wm	AV path	heli
54	Hamill	Hamill	82K/7	4500	ICH	mw2	AV path - old growth	heli
55	Hamill	Hamill	82K/7	4760	ESSF	wm	AV path	heli
56	Toby	Toby	82K/7	5860	ESSF	dkp	AV path	heli
57	Toby	S. Toby	82K/8	5320	ESSF	dk	AV path	heli
58	Toby	Toby	82K/8	6580	ESSF	dk	AV path	heli
59	Hamill	Clint	82K/2	4200	ICH	mw2	AV path - Rip	heli
60	Hamill	Crazy	82K/2	5000	ESSF	wm	Old burn	heli
61	Hamill	Hamill	82K/2	5900	ESSF	wm	AV path	heli
64	Toby	S. Toby	82K/1	5650	ESSF	dk	AV path	heli
65	Hamill	Clint	82K/2	5400	ESSF	wm	AV path - Rip	heli
66	Hamill	Clint	82K/2	4680	ESSF	wm	AV path - Rip	heli
Jumbo Pass	Toby	Jumbo	82K/7	7560	ESSF		sub alpine open	

APPENDIX 2

A Review of Population Estimation Procedures

used for the

1998 Central Purcell Mountains Grizzly Bear Survey

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Preface

This report was prepared as supplemental information to the *1998 Central Purcell Grizzly Bear Survey* report. That report was prepared by AXYS Environmental Consulting Ltd. for Glacier Resorts Ltd. and the British Columbia Environmental Assessment Office.

Executive Summary

Mark-recapture population estimates were obtained for the Central Purcell Study Area grizzly bear population using programs CAPTURE and MARK. Program CAPTURE provides mark-recapture estimates of population size, as well as statistical tests to determine the most applicable model and corresponding estimator to the data. Three issues influence the success of a mark-recapture project. A summary is given of these three issues with a corresponding evaluation of how well each issue was met by the Central Purcell project.

Population closure: Closure is the assumption that there are no births, deaths, immigration or emigration into the study area during the course of sampling. The most probable source of this violation is bears leaving or entering the grid area during the study. The results of statistical tests suggest that closure was violated during the course of sampling. This was most likely due to the small size of the sampling area when compared to potential movements exhibited by bears during sampling. *Therefore, the population estimate from this project should be considered to be unbounded. An unbounded estimate includes the population of bears that reside within and around the mark-recapture sampling grid area.* This estimate cannot be used to calculate population density but it does provide a biologically realistic estimate of the number of bears that utilize the Central Purcell study area.

Another source of closure violation was the mass seasonal movement of bears in later sampling sessions to berry patches. A detailed simulation study was conducted to determine potential biases due to this type of closure violation.

Sample size: Sample size relates to the number of bears, and probabilities of capture for bears within the sampling area. In general the sample size of bears obtained for the Central Purcell study area was adequate for the use of mark-recapture models.

Capture probability variation: Program CAPTURE provides a set of tests which allow a quantitative assessment of how well the population meets the assumptions of mark-recapture models. Complex forms of capture probability were detected in the Central Purcell data set, which complicated the selection of estimation models. A detailed simulation study was conducted to further determine the most appropriate model for the Central Purcell data set.

Thirty three individual grizzly bears were identified in the Central Purcell study area during the course of sampling. Of these, 18 were female and 10 were male (DNA sex tests failed for five bears). Fifteen of the thirty three individuals were caught more than once during the course of sampling.

The results of statistical tests for capture probability variation, and closure violation, as well as the results of simulation studies suggest that the population estimate of 45 bears (M_h (Chao) 95% Confidence interval: 37 to 68 bears) is the best assessment of the population of bears which utilize the mark-recapture grid and surrounding area. Results from Jolly Seber open model analysis further support the population estimate. Simulation results suggest that this estimate may be conservative given the complexity of capture probability variation in the data set.

This data set can also be used to describe the distribution of bears in the sampling area given the large proportion of the population that was identified during sampling (33 of 45 estimated bears). In addition, this data set provides useful insights into optimal designs for potential population monitoring projects.

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1.0 INTRODUCTION

Grizzly bear DNA mark-recapture inventory methods were introduced in 1996 (Woods *et al.*, In press). Since the inception of this technique, DNA mark-recapture has been used to provide population estimates for 2 inventory projects in 1996 and 5 inventory projects in 1997.

1.1 Report Objectives

The principal objective of this report is to evaluate the mark-recapture study design and provide estimates for the 1998 Central Purcell grizzly bear survey area.

1.2 Mark-Recapture Background

Several fundamental mark-recapture concepts must be defined to ensure adequate understanding of the concepts discussed in this report.

1.2.1 Definition of a Model and Estimator

Mark-recapture estimation represents an improvement from traditional count based census methods. With traditional methods, bears would be counted or trapped and the number trapped would be the estimate of population size. Inherent to this is the assumption that all animals have been trapped or counted, otherwise the estimate of population size would be lower than the actual population size. In mark-recapture estimation the percentage of animals captured is estimated. This percentage is called a capture probability, and can be easily expressed by the following formula:

$$\hat{N} = \frac{M}{\hat{p}}$$

Where: M = the census of animals; $\hat{p}$ = the estimate of capture probability; and $\hat{N}$ = the estimate of population size.

With traditional census methods $\hat{p}$ is assumed to equal one.

A *model* is a set of assumptions that correspond to a estimation method. In the case of a census, our model is based on the assumption that all animals are caught. However, capture probability ($\hat{p}$) is actually rarely equal to one and as a result many models have been formulated that make differing assumptions on how $\hat{p}$ varies.

For any model there is a corresponding estimator. An *estimator* is a set of mathematical formulae that allow an estimate using the assumptions of the model. In the case of a count model, the estimate is simply the count of animals caught. The subject of estimation using

mark-recapture methods has seen much theoretical attention, and therefore many estimators exist which are much more complex than simple counts.

In the last 20 years there have been hundreds of publications produced on the subject of mark-recapture (Seber, 1982; White *et al.*, 1982). In addition, there have been a variety of statistical software programs that have been produced to provide mark-recapture estimates from field data sets. The most noteworthy recent programs are program CAPTURE (Otis *et al.*, 1978) and program MARK (White, 1998). Program CAPTURE provides mark-recapture estimates of population size, as well as statistical tests to determine the most applicable model and corresponding estimator to the data. Program MARK is the most recent "state of the art" mark-recapture program. Program MARK's main strength is in the estimate of survival for population monitoring programs, however, it does have limited capacity for population estimates. The main purpose of the Central Purcell grizzly bear survey was to obtain population estimates and therefore program CAPTURE was primarily used.

1.2.2 Bias, Precision and Robustness

Estimates of density and population size are evaluated using two principle measures: precision and bias. The best way to conceptualize precision and bias is to consider what a range of estimates might look like if a project was repeated many times (Figure 1).

Precision is the repeatability of estimates and is usually estimated by the coefficient of variation and the width of confidence intervals. *Bias* is the deviation of estimates from the true population value, and is determined by how well the statistical model and estimator fits the mark-recapture data. The goal of most mark-recapture experiments is to minimize both bias and precision, therefore minimizing potential error in estimates.

An ideal estimator of population size or density should be unbiased, precise, and robust. *Robustness* is a measure of how well an estimator will perform even when its associated assumptions about capture probability are violated. An example of a robust estimator would be one that assumes equal capture probabilities but still gives unbiased estimates when moderate capture probability variation exists in the data.

1.2.3 Key Issues in Optimal Inventory Design

Proper sampling design is critical to obtaining reliable population estimates. The following is a list of the three main issues in inventory design (White *et al.*, 1982).

Meeting the assumption of geographic and demographic closure: If the closed models of program CAPTURE (Otis *et al.*, 1978) are used then it is assumed that the population is closed or "no animals leave, enter, die or are born during the sampling process". Violation of closure can cause substantial biases in estimates from program CAPTURE and reduced estimate precision. It is very difficult to determine statistically from mark-recapture data whether the assumption of closure has been violated. The reason for this is that emigration or immigration from the grid area will appear identical in the data to behavioural response and other forms of capture probability variation (Otis *et al.*, 1978).

Sample size: Sample size is determined by the number of animals in the trapping area, the capture probability of the population, and the number of times the population is sampled. In general, to obtain adequate estimates of smaller populations, higher population capture probabilities are required than for larger populations. The primary effect of low sample size is reduced estimate precision. In addition, if sample size is low, then insufficient data will be available to determine dominant capture probability variations, leading to erroneous model selection with CAPTURE.

Capture probability variation: Grizzly bears probably show unequal probabilities of capture, which can lead to biased population estimates. It is possible to test data to determine the dominant type of capture probability variation if the above issues are met.

Capture probability variation can be divided into three categories:

Heterogeneity: Animals each have a unique probability of capture that is constant throughout the study;
Behavior: Individual animals have an equal initial capture probability which changes after the initial capture; and
Time: The population of bears changes capture probability evenly each time sampling occurs.

Program CAPTURE has estimation models, which are formulated to accommodate each form of variation in capture probability. The CAPTURE models (and corresponding capture probability assumptions) are:

M_o (null or equal capture probabilities);
M_h (heterogeneity);
M_t (time);
M_b (behaviour);
M_{th} (time/heterogeneity);
M_{bh} (behaviour/heterogeneity);
M_{tb} (time/behaviour); and
M_{tbh} (time/behaviour-/heterogeneity).

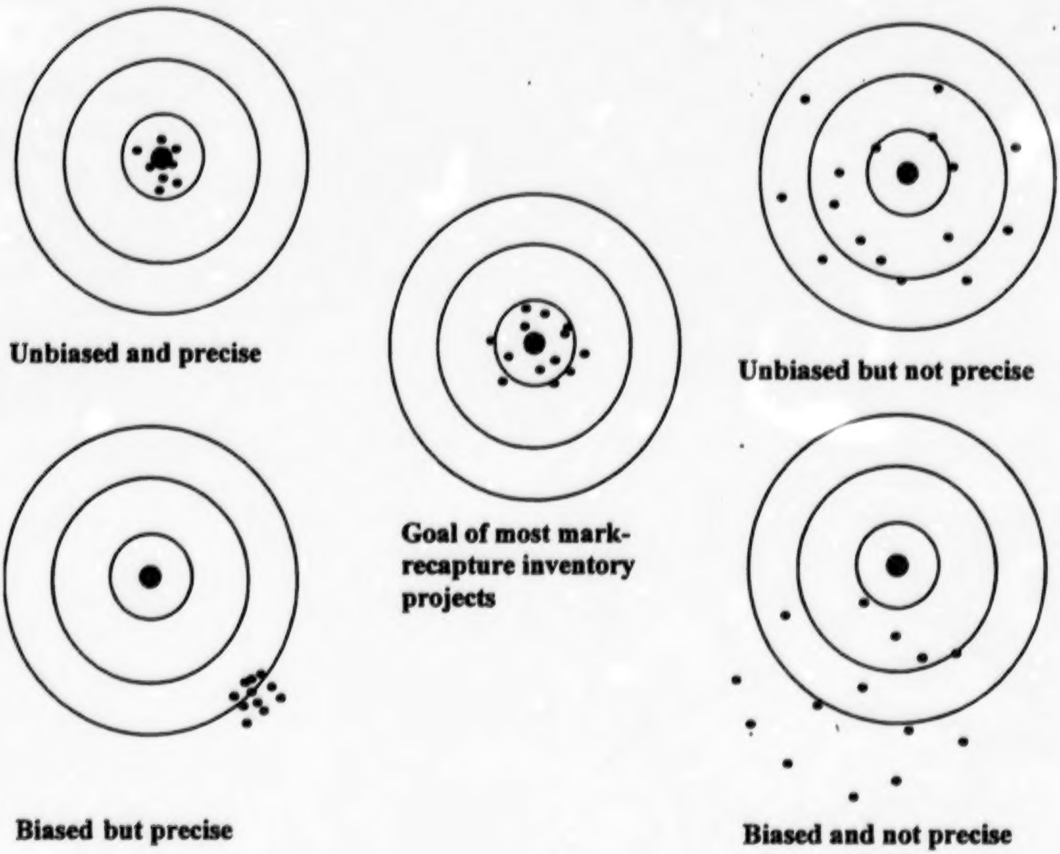
Estimators are available for all models except M_{tbh}.

To meet the goals of an inventory study design, the most appropriate estimation model can be used that will yield the most precise and unbiased results for population estimates.

1.2.4 Definition of Target Population and Population Closure

There are some important conceptual terms in considering the effects of closure on population estimates. Closure can be dichotomized into geographic and demographic closure. Demographic closure is the assumption that there are no births, deaths, immigration or emigration into the study area. Geographic closure is the assumption that the population is limited geographically so that it conforms to the "ball and urn" model of sampling (White *et al.*, 1982). Closed models assume both demographic and geographic closure.

Figure 1: A conceptual diagram of bias and precision



With grizzly bears we can assume that there are no births or deaths during a spring sampling period. Grizzly bears are known to have high survival rates, and spring hunting mortality is carefully controlled and is quite low. Therefore, demographic closure is probably not a significant factor in the bias of estimates.

In most mark-recapture studies it cannot be assumed that the population is completely geographically closed (White *et al.*, 1982). Artificial boundaries in the form of a trapping grid are drawn upon natural populations when a census is conducted. Bears can openly move across these boundaries and therefore it is unrealistic to assume that a population can simply be defined in terms of grid boundaries unless the grid area is much larger than the area through which bears normally travel.

There are two main biological scenarios, which result in geographic closure violation in bear populations. These two scenarios can cause markedly different types of bias in estimates so they are discussed separately.

1.2.4.1 "Edge bear" bias

A portion of bears that reside in the area of the sampling grid will have home ranges that extend beyond the grid boundaries. These "edge bears" may exhibit temporary immigration or emigration from the sampling area during the course of the project. Therefore the actual area that a grid is sampling is larger than the geographic boundaries of the grid. *This will lead to a positive bias in an estimate of population density if the physical area of the sampling grid divides the population estimate.*

If the objective of a project is to sample a target area of interest then it could be argued that the problem of "edge bear" bias is negligible given that an "unbounded" estimate that includes edge bears is a better estimate of the population then a "corrected estimate". For example, a population may initially be 100 bears in a study area at the exact time sampling begins. However, 10 bears may have home range areas that partially overlap the grid area and as a result they may also be sampled during the duration of the project. An estimate corrected for geographic closure would be 100 whereas the unqualified estimate would be 110 bears. It could be argued that the population estimate of 110 that incorporates geographic bias may be a better description of the population that utilizes the study area than the corrected estimate of 100 bears.

The main difficulty arises if the estimates from a project are to be used to calculate an estimate of population density to be extrapolated to larger areas. If an estimate is not corrected then the resulting larger area estimates will be positively biased and highly misleading. This problem, and the problem of similarity of habitat and population density between grid areas and larger areas should be scrutinized thoroughly before any extrapolations are made.

1.2.4.2 Seasonal mass movement bias

Grizzly bears may exhibit mass movements to or from the grid area to select seasonal habitats. For example, bears may move from spring habitat in the sampling area to summer berry habitat outside of the sampling area within the course of sampling (or vice versa). Mass movements or seasonal immigration (or emigration) from the sampling grid can cause a positive or negative bias in population estimates depending on whether bears are entering or leaving the grid area. Of the two, seasonal immigration into the sampling grid has the greatest potential to cause bias (Otis *et al.*, 1978). Restricting sampling to the spring season can minimize mass movement bias.

1.2.4.3 Use of open mark-recapture models to confront closure violation

The Jolly Seber open model in program MARK can partially account for violation of closure by the estimation of permanent emigration and immigration from the grid area during sampling due to seasonal movement of bears. However, the Jolly Seber model will not account for temporary movement of "edge bears" within a sampling session. Therefore, population estimates from the Jolly Seber model should still be considered to be unbounded in the same way as the estimates from closed models.

The utility of the Jolly Seber model for population estimates is limited in the case of the Central Purcell data set because it is not robust to heterogeneity and other forms of capture probability variation. In addition, it usually displays low precision when compared to closed models due to the larger number of demographic parameters incorporated in the estimation process. Therefore, Jolly Seber estimates are best used for comparison with closed model estimates given these limitations.

2.0 ANALYSIS OF DATA

2.1 Sampling Effort

A detailed description of sampling effort and genetic analysis for the Central Purcell survey is provided in the main report. In summary, a grid of 64 5x5 cells was used for sampling. Four eight-day sampling sessions were conducted from 18 June to 25 July 1998. A concurrent sampling design was used in which sites were not moved for each sampling session. DNA from the hair samples were analyzed for species, sex, and individual identification.

2.2 Summary Statistics

Sex classes of bears were pooled and analyzed separately in analysis and estimation efforts for the Central Purcell survey data. Therefore, descriptive statistics are also presented for pooled and separate sex class data.

Table 1: Summary statistics for the 1998 Central Purcell Mountains grizzly bear survey.

Occasion	1	2	3	4	Total
males and females					
Animals caught n(j)=	18	8	13	10	
Total caught M(j)=	0	18	22	31	33
Newly caught u(j)=	18	4	9	2	
Frequencies f(j)=	18	14	1	0	
Females					
Animals caught n(j)=	10	4	5	5	
Total caught M(j)=	0	10	13	17	18
Newly caught u(j)=	10	3	4	1	
Frequencies f(j)=	12	6	0	0	
Males					
Animals caught n(j)=	5	2	6	4	
Total caught M(j)=	0	5	6	10	10
Newly caught u(j)=	5	1	4	0	
Frequencies f(j)=	3	7	0	0	

In Table 1, the "Animals caught" is simply the number of animals (marked and unmarked caught) in each sample. It is an index of the relative effectiveness of sampling efforts. The "Total caught M(j)" describes the number of marked animals in the population at the time of the j^{th} sample. The "Newly caught (uj)" describes the unmarked animals in each sample and indexes the overall effectiveness of the project in sampling the entire population. This number should progressively go down after each occasion if sampling is effective. The "Frequencies of capture" describes the number of times each bear identified or marked in the experiment was caught.

The genetic test for sex failed for five bears and therefore the number of males and females captured do not add up to the total number of bears. This problem will compromise the ability to analyze sex classes separately.

A few trends are apparent from the summary statistics. First, almost half of the bears were recaptured during the course of sampling. This rate of recapture is higher than that observed in other inventory projects in British Columbia (J. Boulanger, unpublished data). Second, almost twice as many females were captured than males. This result should be interpreted cautiously given that the sex test failed for five bears (15% of all captures). The ratio of males to females observed in the Central Purcell survey area (0.56) is similar to the ratio observed from the West Slopes Project in 1997 (0.57) which employed a similar sampling design (Boulanger, 1998).

2.3 Evaluation of Study Design

2.3.1 Sample Size

It has been recommended that the capture probability ($\hat{p}$) of the population being sampled in a mark-recapture study should be above 0.3 for populations less than 100 (White *et al.*, 1982). The capture probability is the relative proportion of the population caught in a sample (0.3 means 30% of the population was assumed to be caught). Further simulation work suggests that capture probabilities of at least 0.2 are required for populations of greater than 100 individuals (Boulanger, 1997). As discussed in Section 2.4 the estimate of population size for the Central Purcell survey area ranges from 39 (M_{bh} (Otto)) to 46 (M_h jackknife)) individual grizzly bears. The capture probabilities corresponding to these estimates is 0.36 and 0.26 respectively. In either case the capture probabilities are marginally at the level recommended by White et al. (1982).

As mentioned earlier, the capture probability levels observed for the Central Purcell survey area population are greater than those observed for other grizzly bear inventory projects in British Columbia. However, the higher capture probability levels observed are offset by the small population size estimated to be in the trapping area. The general result of lower population levels are lower statistical power for model selection, and lower precision of estimates.

2.3.2 Capture Probability Variation

Ten statistical tests to detect variation in capture probability were conducted using program CAPTURE. The results of these tests were then used in a discriminant function analysis procedure implemented in CAPTURE to determine the most appropriate model. The models that fit the data set the best are given higher scores. The model that best represents the data is given a score of 1. A detailed discussion of each statistical test in program CAPTURE is provided in Boulanger, (1997) and White *et al.*, (1982).

Table 2: Capture probability variation and closure violation in the 1998 Central Purcell Mountains grizzly bear survey data set.

	Model rating								Behavioural tests		
SEX CLASSES ANALYZED	M_o	M_h	M_b	M_{bh}	M_t	M_{th}	M_{tb}	M_{tbh}	test 2 (M_b)	test 5 (M_b)	test 7 (M_{bh})
Males & females	0.95	0.88	0.76	0.92	0	0.42	0.79	1.00	0.025	0.12	0.015
Females	0.77	0.68	0.81	1.0	0	0.46	0.69	0.93	0.004	0.312	0.119

Table 2 presents the results of the model selection routine, and tests for behaviour variation from program CAPTURE. Violation of closure can affect the results of the statistical tests in the model selection routine. Other studies suggest that males are the prime culprits in violation of closure and therefore separate analysis of sex classes was used to further discern capture probability variation (Boulanger, 1998). Unfortunately, a low sample size (n = 10 males) precluded valid estimates or inference from the male sex class and therefore only the female sex class is discussed.

Results from the discriminant function procedure in program CAPTURE suggest that model M_{tbh} is most appropriate for the pooled sex classes, and model M_{bh} is most appropriate for the females. The selection of model M_{tbh} for the pooled sex class suggests that all forms of capture probability variation are present and therefore results from any model must be interpreted cautiously. There is no estimator for model M_{tbh} in program CAPTURE because no estimator has been found that can handle this complex of a capture probability structure (Otis *et al.*, 1978).

The results of individual tests for capture probability for the pooled sex class are given in Table 3. Because the data is sparse it is recommended that statistical significance of a test be interpreted at an α level of less than 0.1. If the p-value of a test is less than 0.1 than the null hypothesis for the test is rejected.

Behaviour variation — The results of the model selection test and discriminant function procedure must be interpreted with caution due to bias caused by closure violation. In particular, closure violation will be identical to a behavioural response in the data set. Therefore, the significant results (at $\alpha = 0.1$) of the behavioural response tests (2 and 5) might be caused by closure violation.

Time variation — The presence of time variation in the data set is not surprising given that the time of sampling started in the spring season and ended in the berry season. As noted in other DNA mark-recapture projects, the capture probability of bears usually is reduced in the berry season, as bears are less attracted to the baits of DNA hair-capture stations (Boulanger, 1997). In addition, bears will often exhibit widespread movements to areas of

Table 3. Results from program CAPTURE model selection routine for the 1998 Central Purcell Mountains grizzly bear survey.

Test	Hypothesis: Null	Alternative	χ^2	p	df	Comments
1. General heterogeneity variation	None (M_o)	Hetero-geneity (M_h)	2.38	0.13	1	Hetero-geneity possible
2. General behavioural response after first capture	None (M_o)	Behaviour (M_b)	4.99	0.026	1	Behaviour evident
3. General time variation	None (M_o)	Time (M_t)	6.33	0.097	3	time variation evident
4. Precise heterogeneity	Heterogeneity (M_h)	Not M_h	6.03	0.110	3	Hetero-geneity possible
a) Mh by frequency of capture	Heterogeneity (M_h)	Not M_h	10.8	0.075	3	Hetero-geneity evident
5. Precise behaviour variation	Behaviour (M_b)	Not M_b	7.27	0.121	4	Behaviour evident
a) M_b 1st capture homogeneity across time	Behaviour (M_b)	Not M_b	6.85	0.0325	2	Behaviour evident
b) M_b: Recapture homogeneity across time	Behaviour (M_b)	Not M_b	0.43	0.807	2	Behaviour not evident
6. Precise time variation	Time (M_t)	Not time (M_t)				Expected values too smal1[1]
7. Behavioral response in the presence of heterogeneity	Heterogeneity (M_h)	Behavior & Hetero-geneity	14.1	0.015	5	Behavior & Hetero-geneity

[1]Test failure most likely due to low sample sizes

high berry density. If movement takes bears off the grid then closure is violated as further discussed in Section 2.3.3.

Heterogeneity variation — Heterogeneity variation was marginally detected in tests 1 and 4 of the model selection routine. Heterogeneity is probable given the differences in home range size between male and female bears and subsequent differential trap encounter rates (Boulanger, 1998). Heterogeneity variation has been detected in the data sets of most provincial grizzly bear DNA mark-recapture projects (Boulanger, 1998).

2.3.2.1 Model selection

Model M_{bh} was chosen as appropriate by CAPTURE for the female data set, and as the third most appropriate model for the pooled sex class data set. The M_{bh} (generalized removal)

estimator uses data from first captures only and therefore is less influenced by behavioural variation that is essentially non-independence in capture events. It performs best when there is a decline in new captures throughout capture occasions. In the case of the pooled data the number of new captures does decline from an initial high number (uj=18) of new captures. However, this decline is not constant (uj=18,4,9,2) and it may partially be due to time variation in capture probabilities. Simulation methods will be used to further evaluate the M_{bh} model with the Central Purcell survey data set.

Also worthy of consideration are the M_h (jackknife) and the M_h (Chao) estimators. These estimators are considered to be one of the most robust models in program CAPTURE (Otis *et al.* 1978; Chao 1989). The jackknife estimator is most robust to potential errors in genetic id (Mills *et al.*, In press), as well as mild forms of time and behaviour variation (Otis *et al.* 1978). The M_h jackknife estimator shows superior performance to the M_{bh} estimator when extreme heterogeneity exists in the data set. In this case the M_h jackknife estimator displays unbiased performance whereas the M_{bh} estimator exhibits a negative bias (Pollock & Otto, 1983). The M_h (Chao) estimator was recently introduced into program CAPTURE. It is designed for data in which population size or capture probabilities are low (Chao, 1989).

2.3.3 Population Closure

Of all potential sampling issues, the problem of closure violation has the most potential to bias population estimates with the Central Purcell data set. The degree of closure bias can be evaluated using statistical tests of the data set, examination of bear captures along grid boundaries, and comparison of bear home range areas with the dimensions of the sampling grid.

2.3.3.1 Statistical tests

Two tests were conducted on the data set to determine the degree of closure violation. First the CAPTURE test of Otis et al. (1978) was used to detect general closure violation. Second, a new "JSM$_t$" test by Stanley and Burnham (*In Press*) was used to attempt to determine the type of closure violation. Both of these tests are most sensitive to "mass movement bias" than to "edge bear bias".

CAPTURE Test of Otis et al 1978 — This test is designed to detect immigration or emigration events during the initial or later parts of the study. This test is robust to time and heterogeneity variation but not robust to behaviour variation.

JSM$_t$ Test of Stanley and Burnham (In press) — The JSM$_t$ test of Stanley and Burnham (*In Press*) tests the null hypothesis of the closed model M_t (time variation but no closure violation) against the Jolly-Seber model (Seber, 1982) (open population). This test utilizes the fact that the M_t model is a constrained version of the open Jolly-Seber model. Therefore, the test for closure can be reduced to a goodness of fit test to various constrained versions of the Jolly-Seber model which each make assumptions about the demography of the sampled population. The constrained models that are used in the JSM$_t$ closure test of Stanley and Burnham (*In Press*) are displayed in Table 4.

Table 4. Models used in JSM_t closure test of Stanley and Burnham (*In Press*).

Acronym	Model	Assumptions
JS	Jolly-Seber	Population completely open (migration, births, deaths)
NR	No recruitment	Open with no additions (immigration/births)
NM	No mortality	Open with no losses (emigrations/death)
M_t	Closed M_t	Closed (no additions or losses) but time variation allowed

The JSM_t is a goodness of fit test of closed model M_t versus the open Jolly-Seber model. The JSM_t test further explores closure bias by testing each of the submodels to determine if closure violation is due to additions, losses (or both) to the population during sampling. The JSM_t test is not robust to heterogeneity of capture probabilities and therefore the result of this test should be observed in unison with the CAPTURE test (Stanley & Burnham, *In Press*). The results of the CAPTURE tests and the JSM_t test are shown in Table 5.

Table 5. Results of closure tests with the 1998 Central Purcell Mountains grizzly bear survey data.

Hypothesis			P-values:
Null	**Alternative**	**Tests for...**	**Males & females**
CAPTURE; Otis et al (1978):			
Closed	Not closed	General closure	0.107
JSM_t: Stanley and Burnham (In press)			
M_t	JS	General closure	0.029
1) NR	JS	Additions	0.263
2) M_t	NR	Losses	0.021
3) NM	JS	Losses	0.357
4) M_t	NM	Additions-	0.008

The CAPTURE test failed to detect closure violation at $\alpha = 0.1$; however, a p-value of 0.107 still suggests closure violation. This test has been shown to be reasonably robust to time and heterogeneity variation and therefore this result could only be biased by behaviour variation.

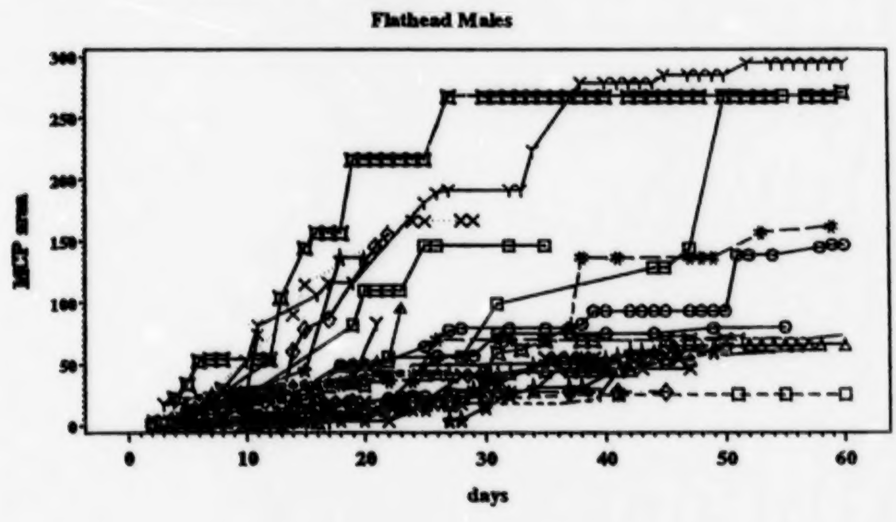
The results of the JSM_t test suggest that closure was violated with the pooled sex class data. Tests 2 and 4 both rejected that both losses and additions could be occurring from the population on the sampling grid in the course of the project. The non-significant results of tests 1 and 3 could be due to the lower power of these tests to detect closure violation (Stanley & Burnham, *In Press*).

In conclusion, statistical tests suggest that closure violation did occur. Given the smaller size of the sampling grid, and the fact that sampling occurred during both the spring and berry season it can be concluded that some degree of seasonal immigration or emigration occurred during the course of sampling. Estimates from the Jolly Seber model (discussed in Section 2.4.2) suggest that permanent emigration did occur during sampling however low estimate precision limits these findings

2.3.3.2 Grizzly bear home range areas versus sampling grid area

The comparison of bear home range areas to the size of the grid area provides indirect evidence of the degree of "edge bear" closure bias that occurred with the Central Purcell data set. Boulanger (1998) conducted an in-depth analysis of home range sizes during the spring season as part of simulation efforts to determine optimal sampling designs. Part of this analysis involved constructing curves that estimate the increase in home range sizes over time. These curves are also useful to determine the area that a grizzly bear might cover during the duration of sampling. The data to construct these curves was taken from grizzly bears radio collared as part of the Flathead bear study (Figure 2; McLellan, 1989). See Boulanger (1998) for a detailed description of the analysis.

Figure 2: Increase in male minimum convex polygon MCP home range size (Mohr, 1947) over time for the spring season.



From Figure 2 it can be seen that some males covered up to 250 km^2 within 40 days which is approximately the duration of sampling in the Central Purcell survey area. This area is equivalent to approximately 10 5x5 km grid cells. A similar curve was constructed for female bears that showed 40 day MCP home range sizes of 25 to 140 km^2. In this case the area covered by a female bear would cover 1 to 5 grid cells. Figure 5 in the main report provides estimates of spring season home range areas from other studies.

From Figure 5 in the main report it can be concluded that male bears can potentially traverse a substantial portion of the sampling area within the time frame of the Central Purcell project sampling period. Alternatively, females could potentially traverse a much reduced area. Therefore, it is very likely that male grizzly bear movements violated the assumption of population closure.

2.3.3.3 Distribution of captures on sampling grid

Study of the distribution of captures on the sampling grid provides indirect evidence of the number of bears that may have traversed the grid boundaries during sampling. Observation of the capture map (Figure 3 in the main report) suggests that a substantial proportion of captures occurred on the southern and western boundary of the grid. Table 6 provides a summary of comments on the closure of boundary cells where captures occurred.

Table 6. Comments on closure of edge cells where bears were captured.

Grid cell #(s)	Area	Comments on closure(within time frame of sampling)
51 and 43	SE	No real barriers for travel off grid. However, most bears caught in these cells were also caught in other cells.
44 and 52	W	In valley corridor (no closure) however most bears captured ≥3 times which suggests bears were on grid for the majority of project.
7 and 20	W	Large icefield minimizes travel off grid however it is still feasible for bears to travel out via high passes.
34	E	In valley corridor, only one bear captured

As explained in Table 6, travel of bears over most of the southern and northern end of the grid was potentially minimized by topography. This is not to say that a bear was not capable of traversing over any of these ridge areas. As further discussed in the main report, bears can easily traverse these ridge areas, or adjacent passes and therefore we cannot be certain that movement was absolutely restricted. The area that probably had the highest degree of closure violation was along the Hamill and Glacier Creek drainage's (Cells 44 and 52). One bear (bear # 35) was captured in three of the sampling periods, and two bears were caught twice (#'s 13 and 23) suggesting that these bears were on the grid for a substantial proportion of the project.

It is difficult to know whether the bears caught on the edge of the sampling area were "edge bears" or bears exhibiting mass movements to or from the grid area. The Central Purcell Project occurred during both the spring and summer berry season. This increased potential movement of bears from spring areas to berry patches (during the latter sampling periods). This would result in increased closure violation. The movement of bears during sampling is further discussed in the main report.

2.3.3.4 *Proper interpretation of estimates given closure bias*

Statistical tests as well as observation of distributions of bear captures on the trapping grid suggest that closure violation did occur during the sampling project. As discussed in Section 1.2.4 closure bias can be a result of temporary emigration/immigration of edge bears or seasonal movement of bears.

Closure bias with edge bears is less relevant if the population estimate from the Central Purcell project is interpreted to include the grid and surrounding area. The extent of the surrounding area is difficult to conclude given that no bears in this study had radio collars to allow tracking of movements. This interpretation does limit the ability to obtain an absolute density estimate from this project for it is difficult to estimate the actual sampling area. *However, as argued in Section 1.2.4, the uncorrected estimate from this project is probably a more realistic estimate of the actual number of bears that traverse and utilize the Central Purcell area. A corrected density estimate falsely implies that the bears exist uniformly across the landscape, and that there is no movement into or out of the grid area.* The problem of seasonal immigration or emigration from the grid area is difficult to interpret given that large biases are possible when seasonal movement occurs. A detailed simulation study of estimator robustness was conducted to address this problem (Section 2.5).

One noteworthy point is that the population estimates (introduced in Section 2.4) from this data set are only slightly larger then the actual number of bears caught. This suggests that sampling was highly effective in documenting bear distribution across the sampling grid. It is the opinion of the author that a more productive use of this data set is to analyze bear distribution on the sampling grid to identify key areas of bear habitat within the grid area.

2.4 Population Estimates

2.4.1 Closed Model Estimates of Population Size

Population estimates for the number of grizzly bears in the Central Purcell Mountains survey area using program CAPTURE are given in Table 7. A few observations can be made about these estimates. First, there is little difference between the estimates of different models. This is due to the fact that the capture probabilities from this data set are fairly high. This is also reflected by the fact that the population estimates are only slightly higher than the actual number of bears identified during the course of the study (M = 33 bears). Second, there is a reasonably high level of precision in estimates with observed coefficient of variation of estimates being below 0.2 (the upper CV level for use of estimates in population management (Pollock *et al.*, 1990).

Table 7. Population estimates for 1998 Central Purcell Mountains grizzly bear survey

Model	Estimator	$\hat{N}$	Standard Error	Confidence Interval[1]		C.V.[2]
Males and Females						
M_o	Null	46	6.76	37	65	0.15
M_h	Jackknife	46	6.01	39	63	0.13
M_{bh}	Otto	35	2.83	33	48	0.08
M_t	Chao	40	4.52	35	55	0.11
M_h	Chao	45	7.13	37	68	0.16
Females						
M_o	Null	30	8.21	20	61	0.27
M_h	Jackknife	29	5.56	23	45	0.19
M_h	Chao	30	9.16	22	63	0.30
M_{bh}	Otto	21	3.46	19	36	0.16

[1]Profile likelihood intervals are given when possible.
[2]Coefficient of variation

As discussed in Section 2.3.2.1, estimates from the M_h (jackknife), M_h (Chao), and M_{bh} estimators should be considered. Of these, the Mh (jackknife and Chao) estimates are more reliable due to the performance of the M_{bh} in simulations (Section 2.5), and the documented robustness of the M_h (jackknife estimator) when compared with the M_{bh} estimator, and other estimators in program CAPTURE (Boulanger & Krebs, 1994; Boulanger & Krebs, 1996; Otis *et al.*, 1978; Pollock & Otto, 1983, Chao, 1989]). The M_h (Chao) and M_h (jackknife) point estimates of population size are similar however the M_h(Chao) exhibits a slightly wider confidence interval and larger coefficient of variation. The M_h (Chao) variance estimate is probably more reliable than the M_h (jackknife) estimate due to the sparseness of the Central Purcell data (Chao, 1989). This topic is explored further in simulations presented in Section 2.5.

2.4.2 Open model estimates of Population Size

Population estimates were also obtained from the Jolly-Seber open model in program MARK (White, 1998). The Jolly Seber model is limited in terms of population estimation (as discussed in Section 1.4.2). Therefore, this analysis was mainly conducted to gain further inference about closure violation, and provide an additional point of inference regarding population size.

The Jolly-Seber model implemented in program MARK estimates relative survival (ϕ), capture probability (p), population size for the first trapping occasion ($\hat{N}_{j=1}$), and the proportional change in population for subsequent trapping occasions (λ). Note that survival in this case mainly considers emigration from the sampling grid since it is improbable that deaths occurred during sampling (White, 1998). In a fully parameterized Jolly Seber model all of the parameters are allowed to vary with time, and estimates for each parameter are therefore produced for most trapping intervals.

The small sample size of marked animals restricted the complexity of Jolly Seber models that could be built from the Central Purcell data set. Given the restrictions of sample size, three candidate models were selected in which each of the parameters was allowed to individually vary with time while other parameters were constant. These models can be symbolized as $\phi.p.\lambda(t)$, $\phi.p(t)\lambda.$, and $\phi(t)p.\lambda.$ where "(t)" signifies time variation and "." signifies constant or no time variation. In addition, a model was considered in which all parameters were constant for each sampling session (denoted $\phi.p.\lambda.$). This suite of model allowed the testing of time effects for each parameter even though sample size constraints did not allow the use of a fully parameterized time model. (i.e.: $\phi(t)p(t)\lambda(t)$). Estimates from each of these models were then averaged (discussed below) therefore incorporating the variability estimates from each model into final parameter estimates.

Model variances were corrected for extra binomial variation using an overdispersion parameter ($\hat{c}$=1.544) estimated by a parametric bootstrap goodness of fit test as described in White, Burnham & Anderson (1999). The most parsimonious model (as indexed by QAICc values) for the data set was one in which survival, capture probability, and proportional population change were constant for all four sampling sessions ($\phi.p.\lambda.$). Parameter estimates from each of the candidate models were averaged using QAICc weights as weighting terms. (Burnham & Anderson, 1998). Analysis of deviance residuals to the full and reduced models suggested an adequate model fit to the data. See Burnham & Anderson (1998) for a detailed discussion of the AIC method of model selection.

The population estimates for the first trapping period from the four averaged candidate models was 46.6 (CI: 6.2 to 86.96). The average rate of change for the population and relative survival during subsequent sampling periods (estimated from model $\phi.p.\lambda.$) was 0.83 (CI: 0.52 to 0.96) was 0.82 (CI: 0.31 to 0.98) respectively. The estimates of survival and rate of change suggests the population was potentially decreasing (due to emigration) during sampling however the large width of the confidence interval limits the amount of inference that can be drawn from these estimates.

A few factors should be considered when interpreting the Jolly-Seber parameter estimates. First, the low precision (CV=0.44) limits the interpretation of the estimate. The large number of parameters used in the estimation process has been shown to limit the precision of population estimates from the Jolly Seber model with sparse data sets (Pollock et al., 1990; Seber, 1982). In addition, the Jolly-Seber model has been shown to be negatively biased in the presence of heterogeneity which is present in the Central Purcell data set (Pollock et al., 1990). However, the fact that a similar estimate is produced by both closed ($\hat{N}_{j=1}$(Chao)=45) and Jolly Seber open models ($\hat{N}_{j=1}$=46.6) further supports the estimate of the population of bears from this data set.

2.4.3 Conclusions

The agreement of open and closed model estimates further supports the proposed population estimates. As mentioned earlier, the estimates of closed models are more reliable given the non-robustness of the Jolly Seber model to heterogeneity variation. However, the Jolly Seber analysis, as well as results of the JSMt test suggest that mass movement or permanent emigration bias may be evident in the data set. Therefore, simulation tests of were conducted to further test closed model estimator robustness to these sample biases.

2.5 Simulation Evaluation of Estimators

Both closure violation and complex (M_{tbh}) capture probability variation can cause bias in mark-recapture estimates from the Central Purcell project. Two separate simulation studies were conducted to explore estimator robustness to these factors. Open models were not considered in these simulations given their poor performance as discussed in Section 2.4.2.

2.5.1 Estimator Robustness to Mass Movement and Closure Bias

Published evaluation of estimators make it possible to conclude that the M_h jackknife estimator is most robust to the forms of capture probability variation detected in the data. However, the problem of mass movement and corresponding potential bias should also be considered to allow a full evaluation of population estimates.

The problem of closure bias is simplified if it is considered that the population estimate for the Central Purcell survey area includes the population of "resident" bears in the grid area and surrounding area. The main concern about bias is reduced to the question of whether the population estimate is not significantly biased by mass movements of bears from the sampling area. While mass movement bias has been acknowledge in the literature (Otis *et al.*, 1978) there has been little theoretical study of estimator robustness to this type of bias.

A Monte Carlo simulation study was conducted to determine the robustness of estimators to mass movements of bears from the sampling area. In these simulations, varying levels of immigration and emigration from the grid area were simulated. In addition, various underlying capture probability models were used to determine the possible biases caused by interactions of capture probability variation and closure bias. Estimates were then compared to the initial population number of bears in the sampling area. Robustness in this case was judged by whether an estimator maintained a consistent level of bias over varying levels of mass movement from the sampling area.

2.5.1.1 What is Monte Carlo Simulation?

Monte Carlo simulation is a powerful statistical technique in which a computer model generates hundreds of hypothetical data sets that are simulations of particular sample biases. Each of these hypothetical data sets is run through estimators in program CAPTURE. Through analysis of the resulting estimates, relative bias, and precision of estimation, models can be determined because the true population number is known, and the degree of sample bias is known.

The concept of Monte Carlo simulation is similar to the "target shoot" analogy given in Figure 1. Through the course of a simulation estimators produce hundreds of shots (estimates) at a hypothetical target in which the bullseye is the true population size. The dispersion of these shots and how close to the bullseye the shots are is dependent on how robust the estimators are to the simulated sample bias. It is impossible to know how well any one simulated data set ("one shot") pertains to actual field data. Instead, it is assumed that collectively the simulated data pertains to potential biases inherent in the field data set. Given this, absolute bias of estimates cannot be inferred from Monte Carlo simulation however the relative robustness of estimators to sample biases can be inferred. In addition, these simulations address biases particular to the Central Purcell data set and should not be interpreted generally.

2.5.1.2 Simulation methods

The degree of simulated capture probability variation was estimated from the data. The number of animals captured for each sampling occasion (nj=18, 8,13,10) was used to estimate time variation. The capture probabilities for each sex class ($\hat{p}_{males}$= 0.35. $\hat{p}_{females}$=0.2) as estimated by the heterogeneity model (M_h (jackknife)) was used to estimate the degree of heterogeneity variation. Additional heterogeneity variation was included by simulating these mean values as normally distributed random variates with a standard deviation equal to 30% of the mean capture probability value. These parameters were used to formulate underlying models that simulated heterogeneity, time, and time/heterogeneity variation.

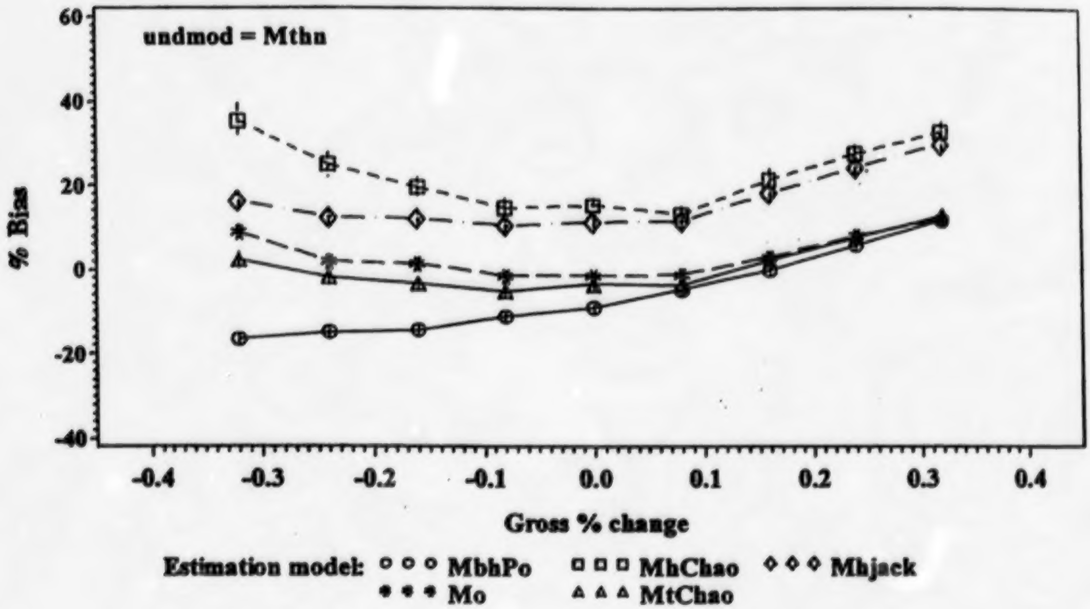
Removing or adding a constant percentage of bears to the data set following each sampling period simulated emigration and immigration. For example, 4% of the population of bears was removed for each sampling period to simulate a gross emigration rate of 16% (4 periods x 4%/period) for the entire sampling period. The starting population size of bears for each simulation was 46 bears. Note that it is assumed that movement from the sampling area occurred incrementally throughout the period of sampling in this simulation.

Percent relative bias was calculated as the difference between the estimated population minus the true population divided by the true population size. Simulations were programmed in Microsoft Visual Basic. A version of program CAPTURE modified by the author to generate abridged output files was used to generate estimates.

2.5.1.3 Results

In general, it was found that most estimators were reasonably robust to moderate rates of emigration and immigration as long as the starting population size was used for the calculation of bias. Large biases were evident if the midpoint or ending population size was used as a measure of bias. Of estimators that were compared, the M_{bh} estimator was least robust and the M_h jackknife was the most robust. the results from one of the simulations in which time and heterogeneity variation was simulated is displayed in Figure 3. Emigration is indexed by a negative gross change and immigration as a positive gross change.

Figure 3: Percent relative bias of estimators (based on initial population size) when varying levels of emigration and immigration from the sampling area was simulated. Time and heterogeneity variation was also simulated.



From Figure 3 it can be seen that the M_h (jackknife), M_o and M_t (Chao) estimators are the most robust showing a consistent bias across varying levels of gross change in population size whereas the M_{bh} estimator is least robust showing an increasing bias across levels of gross change. It is important to note that the simulations are designed to test robustness of estimators to varying levels of movement and therefore it cannot be concluded that the results from any simulation can be used to estimate bias in the actual data set.

2.5.2 Robustness of Estimators to Complex Capture Probability Structure

Model M_{tbh} or a model incorporating time, behaviour, and the program CAPTURE model selection routine as the most appropriate model for the Central Purcell data set picked heterogeneity variation. There is no estimator that is presently available to handle all three forms of capture probability variation simultaneously. Given this problem it is essential to use Monte Carlo Simulation to explore robustness of estimators to M_{tbh} variation.

A small set of simulations was conducted in which time, heterogeneity, and behaviour variation was simulated. The program CAPTURE simulation module was used for these simulations (as opposed to the previously described simulation model) because of its ability to simulate complex capture probability models. The parameterization of heterogeneity and time variation was similar to that described for the previous model (Section 2.5.4). Three forms of behaviour variation

were simulated in which bears exhibited a "trap shy" response (capture probability decreases by 20% each time a bear is captured), and "trap happy" response (capture probability increases by 30% each time a bear is captured). The M_h jackknife M_h (Chao), and M_{bh} estimation models were then tested using the simulated data. A population of 40 bears sampled for 4 sessions was used as in the previous simulations.

In general, all estimators exhibited a negative bias when time, heterogeneity, and behaviour variation was simulated. The degree of negative bias was very much determined by the strength of heterogeneity variation simulated. In terms of bias the M_h (Chao) estimator showed the least bias, followed by the M_h(jackknife) and the M_{bh} (Otto) estimators. The M_h (Chao) estimator showed approximately unbiased results whereas the jackknife and M_{bh} estimators exhibited biases of -20 and -40 percent respectively. Again, it is difficult to determine the exact bias in estimates from these simulations, but we can conclude the M_h (Chao) estimator is most robust of the estimators considered. In general, it can also be concluded that estimates from all estimators will most likely be conservative or negatively biased when time, behaviour and heterogeneity variation exist in the data set. This conclusion is further supported by the results of published simulation studies of estimators (Boulanger & Krebs, 1996).

There is also a high likelihood of negative bias of variance estimates and associated confidence interval widths due to the presence of time, behaviour, and heterogeneity variation. This basically leads to confidence intervals which show lower coverage than the specified 95% level. Simulation results showed the confidence interval coverage of the M_h (Chao) estimator was the best varying from the 70% level whereas the M_h (jackknife) and M_{bh} estimators exhibited lower levels of coverage The conclusion that the estimate of survey variance of the Chao estimator is most reliable is also supported by published simulation evaluations of estimators (Chao, 1989).

2.5.3 Conclusion of Simulations

The results of simulations presented in this report and results of simulations in the published literature (Boulanger & Krebs, 1996; Otis *et al.*, 1978; Pollock & Otto, 1983) suggest that the M_h (Jackknife) estimator is the most robust estimator to mass movements that are probable in the data set. Results of capture probability simulations suggest that the M_h (Chao) estimator is most robust to the complex form of capture probability variation detected in the Central Purcell data set. *Results of simulations also suggest that the presence of time, heterogeneity, and behaviour capture probability variation most likely will cause estimates to be conservative.*

The estimates of population size from the M_h (jackknife) and M_h (Chao) estimator are very close (45 and 46 bears). Either of these estimates can therefore be used to describe the population in the Central Purcell Mountains survey area given the similarity of estimates, and relative strengths of each estimator revealed in the simulation trials. However, the confidence interval width of the M_h (Chao) estimator should be used to describe the precision of estimates obtained in this study.

3.0 CONCLUSIONS

3.1 Proper Interpretation of Estimates

The population estimates of 45 bears from the M_h (Chao) estimator is the most reliable estimate of those considered in this paper. The violation of closure prohibits the estimation of absolute density for the Central Purcell project. However, the "unbounded" population estimate obtained (which relates to the grid and surrounding area) is still a valid estimate of the number of bears that utilize the Central Purcell survey area. It could be argued that this estimate is a better biological description of the population of bears in the area given the small size of the area sampled, and the inevitable fact that bears in the surrounding area do use the Central Purcell survey area.

4.0 RECOMMENDATIONS

4.1 Population Monitoring

The sampling design used in the Central Purcell Project is optimal if the objective is to monitor population trends by replicating sampling efforts for more than one year. This is due to the fact that the estimates from the Central Purcell Project had a high level of precision. Bias is less important for determination of trend, for estimates only have to show consistent bias across years to allow a calculation of population change.

Simulations were conducted to determine the power of the sampling design used in the Central Purcell Project to detect hypothetical population changes. A simulation was conducted in which this project was every year for six occasions. The power to detect a hypothesized change was estimated (with α=0.2, and a 1-tailed test). Levels of precision as estimated by the M_h(Chao) estimator were used for power calculations. Program MONITOR (Gibbs 1995) and program TRENDS (Gerrodette 1987) were used for power calculations. The power to detect a 35% positive or negative change in population size after 6 years was 0.94 and 0.79 respectively. Greater sampling effort (i.e. more sampling sessions) would have to be implemented to ensure adequate power to detect smaller population changes. This estimate of power is considered conservative given that it may be possible to use more powerful mark-recapture models with the hypothetical long-term data set (Lebreton *et al.* 1992; Anderson and Burnham 1995). A more detailed analysis of potential monitoring studies should be undertaken before future projects are implemented. However, it can be concluded that the Central Purcell project design is the most cost-efficient methodology to monitor populations.

4.2 Density Estimates

The primary objective of the Central Purcell project was to obtain an unbounded population estimate. The unbounded estimate represents the general number of bears that utilize the Central Purcell survey area. If the objective of future projects is to obtain absolute density estimates then a larger grid size and sequential sampling design should be employed. For example, most inventory projects in BC have used a sampling design with at least 64 8x8 km cells for estimates of absolute abundance. Simulation work suggests that the 64 8x8 km grid cell size is the absolute minimum size and grids more cells are desirable to minimize closure bias. The best design would be to radio collar a proportion of bears to allow an empirical assessment of the degree of closure violation (Boulanger, 1998)

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